See D1021 4/30/86
J. Pohle
BWIP Conceptual Model

U.S NUCLEAR REGULATORY COMMISSION
DIVISION OF WASTE MANAGEMENT

DEVELOPMENT OF GROUNDWATER CONCEPTUAL FLOW MODELS FOR THE BWIP SITE

SUBTASK 2.4

TECHNICAL ASSISTANCE IN HYDROGEOLOGY
PROJECT B - ANALYSIS
RS-NMS-85-009

April 30, 1986

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April 30, 1986

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Attn: Mr. Mark Logsdon, Project Manager
Technical Assistance in Hydrology,
Project B (RS-NMS-85-009)

Re: Report: Development of BWIP Groundwater Conceptual Flow Models

Dear Mr. Logsdon:

Please find the attached report entitled, Development of BWIP Groundwater Conceptual Flow Models. This report presents Terra Therma's current concepts regarding the groundwater flow system at the BWIP site. Our approach has been to evaluate these concepts from the standpoint of regulatory issues which must be addressed by the NRC in their licencing function. In addition, we propose work plans to further study groundwater flow/transport concepts which currently have a high degree of uncertainty, but will be important to the NRC in reaching regulatory decisions.

Please do not hesitate to contact us if you have any questions regarding this report.

Respectfully submitted,
TERRA THERMA, INC.

Fred Marinelli for Mike Galloway

Mike Galloway, President

U.S NUCLEAR REGULATORY COMMISSION
DIVISION OF WASTE MANAGEMENT

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1.0 CONCEPTUAL MODELS: PHILOSOPHY AND CONCEPTS

1.1 INTRODUCTION

Whether called conceptual models, multiple working hypotheses, or just ideas, the concept of defining possible parameters, relationships, and/or descriptions to accurately simulate a system or process that cannot be directly observed has always been the basis of scientific discovery. Since the earth sciences are usually limited to indirect observation, models have provided the framework from which details and processes can be observed or defined. The plate tectonics revolution is a perfect example of a conceptual model, the data availability needed to support or refute a model, and the "data needs" which resulted from the conceptual model.

In the early 20th century, Alfred Wegner (1924) proposed the idea of drifting continents to explain certain observations which had perplexed geologists for years. During work in Greenland, he became intrigued with how well opposite coastlines throughout the world matched one another. However, it was not until he read paleontological accounts of non-mobile species which were common to opposing continents that he began to seriously explore this idea. His conceptual model of the earth was received with mixed interest, primarily because a critical piece of the puzzle was absent. This necessary puzzle piece was a satisfactory mechanism for drifting continents which could be supported by both physical laws and observations.

At this stage, the conceptual model of continental drift was modified, expanded, and/or discarded by numerous researchers. The model explained several curious observations but did not seem to be a viable "simulation" of past and present processes. During the mid to late 1960's, independent research projects provided the basic data which would lead to a revolution in geologic thought. After considerable puzzlement over striped magnetic patterns measured on the ocean floors, researchers used recent observations of polarity changes in the earth's magnetic field to develop the idea of sea-floor spreading along well-defined ridges or spreading zones. It quickly became apparent that the continents were not ships but rather rafts passively riding on crustal material which was being destroyed and created along specific identifiable zones. This provided the satisfactory mechanism needed to explain the idea of continental drift/plate tectonics. In a very short time, the geologic community embraced this model and applied it to processes no one had even considered just a few years previously, such as metal and petroleum occurrences.

The continental drift story is an example of a feedback loop between an evolving conceptual model, parametric data, and observed responses. The continental drift conceptual model has been and will continue to be modified as knowledge about the earth increases. Although embodying much of the preceding discussion, a more precise definition of conceptual models is provided below.

A conceptual model of a system includes the minimum features of the real system which are needed to qualitatively determine the relevant behavior of the system. A conceptual model should be a concept or an abstraction. This implies that not everything in the model must be precisely known. However, the concept must include the relevant general operational features of the real system. No aspect of the real system that is important to determining the relevant system behavior at the desired level of detail should be missing from the model.

A conceptual model should be a model. That is, it should be an analog of the real system, and should reproduce the behavior of the system to the required level of accuracy when its input parameters and conditions are specified. A conceptual model should be use oriented. This suggests that the model may relate to only one aspect of the system in order to keep it relevant to the problem of interest. A conceptual model should be minimal. That is, the model should not contain any factors that are unnecessary for the use to which the model is put, and that the model should not contain any aspects that could be deduced from an analysis using other information provided in the model. A conceptual model is the basis for construction of analog, analytical, and numerical models in which numerical values are assigned to model parameters and quantitative results are obtained.

A further feature of a conceptual model, in the geohydrology usage, is that it is generally accepted that a conceptual model will change as knowledge of site conditions increases. Thus it refers to a living concept, rather than a determined system: a hypothesis, rather than a fact.

1.2 CONCEPTS OF BWIP CONCEPTUAL MODELS

The information used in conceptual model development can be divided into five categories: 1) framework, 2) parametric data, 3) boundary conditions, 4) stimuli, and 5) responses. In this document, conceptual models are assumed to include the framework, parametric data, boundary conditions, and in the case of non-steady state models, the stimuli. Responses are not considered to be part of the conceptual model, but yet are dependent upon the model and provide feedback which might change the model.

At BWIP, the framework includes the rigid structure within which the processes occur. The physical qualities of the various rock units, such as thickness, geometry, and continuity, and geologic structures, such as faults and joints, are examples of data that make up the framework. Parametric data include the hydraulic characteristics of rock units and structures. The geometry and hydraulic characteristics of the model's boundaries together with the framework and parametric data provide the basis of the conceptual model. In the case of modeling non-steady state situations, such as a long-term aquifer test or actual repository placement within the natural system, additional modifications are made to the model through the stimuli category. Responses include both observed data, such as hydraulic heads (and therefore gradients) and some aspects of the hydrochemistry, and calculated information such as flow directions, velocities, and fluxes.

In developing a conceptual model, observed responses must provide immediate feedback to the development process. This feedback loop is such an integral part of the development process that the definition of what is in the model and what is outside the model becomes somewhat blurred. Without the feedback of the observed data (such as hydraulic heads), the validity of any conceptual model would be in question as a predictive tool or concept and/or as the basis of any quantitative modeling. If the comparison at such a fundamental level does not work, the model components must be reviewed. Once the model reaches the level of quantitative analysis, the imaginary limits of the model become more distinct and better defined. The model is now represented as an equation or series of equations, and the results as the solution. The equal sign becomes the limit of the model. In a conceptual model stage, there is no equal sign at its limits, but rather a comparative thought process.

2.0 HISTORICAL DEVELOPMENT OF BWIP CONCEPTUAL MODELS

Development of groundwater conceptual flow models for the BWIP site is an ongoing process to be refined and/or modified as additional data become available. Throughout this process, there has been general agreement on certain components of the flow system. For example, nearly all investigators consider Columbia River Basalt to constitute a layered system in which interflows have relatively high transmissivity and flow interiors provide a certain degree of confinement. Other components of the proposed models differ substantially, such as the significance of vertical leakage on the regional scale and assumed boundary conditions. Terra Therma does not necessarily subscribe to data needs associated with the models presented in this Section. Our detailed approach to data needs assessment is discussed in Section 6.

A summary of conceptual model development prior to the BWIP Site Characterization Report (SCR) was presented in a tabular format (DOE, 1982). This information is reproduced in its original form in Table 2.1. These models were not generally comprehensive and tended to concentrate on specific components of the flow system. Pre-SCR models typically made a distinction between unconfined and confined (basalt) flow systems and recognized the apparent permeability contrast between interflows and flow interiors. Uncertainties, disagreements, and omissions existed in the assumed boundary conditions, flow directions, degree of hydrologic isolation between basalt units, and importance of structural discontinuities. It was recognized by all

Table 2.1

Primary References for Hydrologic Testing Data and Conceptual Models. (Sheet 1 of 3) **Source: DOE (1982)**

Investigator(s), purpose of study, and work accomplished	Hydrologic properties			Hydraulic heads	Groundwater-recharge area	Groundwater-discharge area	Other
	Hydraulic conductivity (m/s)	Storativity	Porosity				
Raymond and Tillson (1968), Battelle, Pacific Northwest Laboratories In situ testing of existing borehole RSH-1. Funding from U.S. Atomic Energy Commission to measure hydrogeologic properties of basalt pertinent to radioactive waste-storage considerations. Results of geophysical logging, seven drill-stem tests, seven head measurements, and palynology studies reported.	Flow top 10^{-7} to 10^{-11} Columnar zones 10^{-10} to 10^{-11}	None given	Total porosity estimated from neutron logs to be 3 to 6% for the columnar zones.	Values questionable because the hole was open for 10 yr prior to testing. Data might suggest head decreases with depth.	Not addressed	Not addressed	Authors noted that water quality and drill-stem tests suggest that "there is a high degree of formation water isolation between major sections penetrated by the well."
LaSala and Doty (1971), U.S. Geological Survey In situ testing of existing borehole DC-1. Study done in support of U.S. Atomic Energy Commission's effort to evaluate feasibility of storing radioactive waste in basalt beneath the Hanford Site. Hydrologic tests conducted include 4 pumping, 11 fluid-injection/withdrawal, and 22 head measurements. Water samples were also collected.	Flow tops 10^{-6} to 10^{-9} No tests conducted solely across columnar zones	(Mostly composite tests) 10^{-3} to 10^{-6}	Total porosity values from core samples of flow tops ranged from 10 to 25%. Single core sample from columnar zone had 2% total porosity. Overall porosity values are poorly known.	Essentially no head gradient in Wanapum and upper Grande Ronde Basalts. Head decreases with depth below Umtanum flow of Grande Ronde Basalt.	Recharge occurs along the ridges and plateaus surrounding the Pasco Basin.	Discharge is to the Columbia River, perhaps near Wallula Gap south of the Hanford Site.	Distinct hydrochemical zonation exists. Shallow groundwaters are $Na\text{-}HCO_3$ chemical types, while deeper waters are $Na\text{-}HCO_3,Cl$ types. This zonation plus small head gradients suggest, "that little, if any, vertical movement of water has occurred at the site of DC-1."
LaSala et al. (1972), U.S. Geological Survey Study of regional groundwater flow in south-central Washington as part of the the U.S. Atomic Energy Commission's research into managing radioactive wastes stored on the Hanford Site. Data are mostly from existing records and documentation. Composite groundwater samples collected from 22 existing shallow wells (150 to 450 m deep) distributed across south-central Washington.	Generally repeated data from LaSala and Doty (1971) for DC-1. Note that average hydraulic conductivity for flow tops in Wanapum and Grande Ronde Basalts was 10^{-6} m/s. "Flow tops make up a small percentage of the total basaltic rock section."			Groundwater flow controlled by topography, geologic structures, and placement of major rivers. Beneath the Hanford Site, groundwater moves southeast. Groundwater northeast and east of Hanford flows southwest toward the Columbia River.	Recharge occurs on the ridges and plateaus fringing the Pasco Basin. Water recharged during last glacial period.	Discharge is to the Columbia River south of the Hanford Site.	Intrabasin groundwater transfer not fully understood due to lack of data. Shallow basalt groundwaters of an $Na,Mg\text{-}HCO_3$ chemical type, while deeper groundwaters are of $NaHCO_3,Cl$ type. Adjusted groundwater ages for shallow basalt waters beneath Hanford Site are 12,000 to 30,000 yr old.
ARHCO (1976), Atlantic Richfield Hanford Company Summarization of earlier studies found to be valuable in qualifying Columbia River basalt for storage of commercial radioactive waste. Work funded by the Office of Waste Isolation, Union Carbide Corporation.	Data reported principally from the above three reports, plus ERDA (1975).			Uppermost flow system in Saddle Mountains Basalt flows in east-to-southeast direction beneath Hanford Site. At DC-1, heads from 5 piezometers appear to indicate a slight upward gradient in Grande Ronde Basalt.	Recharge is from precipitation on ridges where basalt is exposed, surface runoff into coulees, and irrigation.	Discharge is to the Columbia River (no location specified).	Emphasized the need to drill and test in existing and new boreholes. Based upon these data, numerical models should be developed to better understand flow-system dynamics, as well as evaluating the potential for long-term isolation of radioactive waste in basalt. The authors noted that vertical exchange of groundwaters between different flow systems might occur along local areas near major anticlines.

TABLE 2.1 CONCEPTUAL MODELS PRIOR TO BWIP SITE CHARACTERIZATION REPORT

Primary References for Hydrologic Testing Data and Conceptual Models. (Sheet 2 of 3) Source: DOE (1982)

Investigator(s), purpose of study, and work accomplished	Hydrologic properties			Hydraulic heads	Groundwater-recharge area	Groundwater-discharge area	Other
	Hydraulic conductivity (m/s)	Storativity	Porosity				
SAI (1978), Science Applications, Inc. In situ hydrologic tests in borehole DC-2. Completed six injection tests and two head measurements. Study sponsored by the Basalt Waste Isolation Project, Rockwell Hanford Operations.	Flow tops 10^{-8} to 10^{-9} Columnar zones 10^{-5} to 10^{-11}	10^{-3} to 10^{-6}	Not addressed	Two head values across flow tops in Grande Ronde Basalt. Insufficient data to develop reliable gradient.	Not addressed	Not addressed	
Summers et al. (1978), W. K. Summers and Associates Compiled hydrologic data available from wells in Pasco Basin and summarized a conceptual model that might be inferred from these data. Study sponsored by the Basalt Waste Isolation Project, Rockwell Hanford Operations.	Flow tops and intervals 10^{-4} to 10^{-5} From composite of specific-capacity tests in irrigation wells.	10^{-3} to 10^{-4}	Referenced total porosity values given in Raymond and Tillson (1968), LaSala and Doty (1971), and Agapito et al. (1977). This last reference reports total porosities of 0.6 to 12.9% from 14 core analyses.	References existing data. From composite water levels in irrigation wells (available from Washington State Department of Ecology). The head decreases toward the Columbia and Snake Rivers. This implies groundwater flow is toward the major rivers.	Recharge occurs in the surrounding hills and mountains, plus irrigation.	Local and intermediate flow systems discharged to the nearby rivers. Regional flow system discharges west of the Pasco Basin.	Authors noted that hydrologic data within the Pasco Basin were very limited, except within the Hanford Site. Because of this, the conceptual model they developed, depicting local, intermediate, and regional flow systems, did not represent data in real space. Therefore, the model developed was, rather, that which might exist based upon hydrologic principles and the geologic setting.
Gephart et al. (1979a), Rockwell Hanford Operations Seven drill-stem tests in the Grande Ronde Basalt of borehole RSH-1. Caliper, 3-dimensional velocity, and seisviewer geophysical logs were run in selected zones. Study conducted by the Basalt Waste Isolation Project, Rockwell Hanford Operations.	Flow tops 10^{-7} to 10^{-11}	Not addressed	Not addressed	Not attempted. Reliable head measurements were not possible, since the borehole had been open for 20 yr prior to study.	Not addressed	Not addressed	Work conducted in 1977.
Tanaka et al. (1979), Washington State Department of Ecology Compiled existing hydrologic data for basalt in the Washington State portion of the Columbia Plateau. Study was sponsored by the Basalt Waste Isolation Project, Rockwell Hanford Operations.	Flow tops and interbeds ~10^{-4} to 10^{-7} From composite of specific-capacity tests.	10^{-4} to 10^{-4}	Not addressed	Composite potentiometric maps suggest overall groundwater flow in Washington State portion of Columbia Plateau is toward the Pasco Basin.	Recharge is from precipitation on basalt outcrops, plus irrigation.	Discharge is to the Columbia River and its tributaries, where basalt and river are in direct contact. Water is also removed by irrigation pumping.	Intrabasin groundwater movement considered important.
Apps et al. (1979), Lawrence Berkeley Laboratory Six head measurements and one groundwater sample from Grande Ronde Basalt in borehole DC-2. Fifteen head measurements, 12 flow tests, and 1 water sample from Grande Ronde Basalt in borehole DC-6. Four head measurements from Wanapum Basalt in borehole DC-8. Study was sponsored by the U.S. Department of Energy and Basalt Waste Isolation Project, Rockwell Hanford Operations. This study was part of the feasibility study on the waste-isolation potential of basalt.	Flow tops 10^{-5} to 10^{-9}, mostly from composite flow testing	Referenced earlier reports.		Variable head pattern in Wanapum Basalt at DC-8 and Grande Ronde Basalt at DC-6. Slight head decrease with depth in Grande Ronde at DC-2. Available evidence suggests groundwater movement is parallel to the Cold Creek syncline.	Local recharge is from surrounding hills. Regional recharge is from areas outside the Pasco Basin.	Discharge is to the Columbia River at or south of the Tri-Cities.	Areas of extensive faulting and/or folding can form flow barriers to horizontal groundwater movement and maximum vertical permeability. Conceptual model consisted of two layers: an upper sedimentary layer (unconfined aquifer) and a lower layer consisting totally of basalt. Several groundwater-flow systems may exist in the basalts, each with its own geometry, recharge/discharge areas, etc. Deeper, regional systems could encompass much larger areas than shallower systems.

TABLE 2.1 (cont.)

Primary References for Hydrologic Testing Data and Conceptual Models. (Sheet 3 of 3)

Source: DOE (1982)

Investigator(s), purpose of study, and work accomplished	Hydrologic properties			Hydraulic heads	Groundwater-recharge area	Groundwater-discharge area	Other
	Hydraulic conductivity (m/s)	Storativity	Porosity				
Gephart et al. (1979b), Rockwell Hanford Operations Integrated and evaluated existing hydrologic knowledge, specifically within the Pasco Basin, but also across the Washington State portion of the Columbia Plateau. New data reported included ~20 head measurements, 12 pumping tests, and hydrochemical analyses from 19, 12, and 3 well sites, respectively, in the Saddle Mountains, Wanapum, and Grande Ronde Basalts. Study conducted by the Basalt Waste Isolation Project, Rockwell Hanford Operations.	Flow tops and interbeds: Saddle Mountains 10^{-3} to 10^{-6} (median 10^{-5}) Wanapum 10^{-2} to 10^{-8} (median 10^{-3}) Grande Ronde 10^{-4} to 10^{-11} (median 10^{-8}) Columnar zones: Horizontal 10^{-9} to 10^{-14} (median 10^{-12}) Vertical 10^{-9} to 10^{-12} (model estimated)	Flow tops 10^{-3} to 10^{-4} Columnar zones 10^{-5} to 10^{-6}	Referenced same values as given by Raymond and Tillson (1968), LaSala and Doty (1971), and Agapito et al. (1977).	Potentiometric map for Mabton interbed suggests groundwater flows generally southwest across the Hanford Site. Composite potentiometric head maps for the Saddle Mountains and Wanapum Basalts across the Columbia Plateau indicate groundwater flow is toward the Pasco Basin. Within the Hanford Site, it was suggested that little head gradient existed in the Wanapum or upper Grande Ronde Basalt. Data also suggested that the Umtanum Ridge-Gable Mountain anticline forms a structural barrier to groundwater flow.	The Saddle Mountains Basalts are recharged from precipitation falling on the basalt outcrops rimming the Pasco Basin. Wanapum and Grande Ronde Basalts are recharged both locally and from surrounding basins. Artificial recharge important in areas of extensive irrigation.	Shallow flow systems discharge to the unconfined aquifer and to major rivers. Deeper, regional systems in the Wanapum and Grande Ronde Basalts discharge to rivers south of the Hanford Site, most likely near Wallula Gap.	The overall conceptual model consisted of an upper unconfined aquifer overlying confined aquifers within each of the principal basalt formations. These confined systems were thought to be categorized as local, intermediate, and regional systems. Major hydrochemical differences are evident between the Saddle Mountains and Grande Ronde groundwaters. The columnar zones of basalt flows act as low-permeability aquitards, separating higher permeable interbeds and flow tops. Little vertical groundwater mixing exists between different flow systems, except along anticlines, near major faulting, or where erosion has worn away the confining basalt units.
Dove et al. (1981), Pacific Northwest Laboratory A technical demonstration of the Assessment of Effectiveness of Geologic Isolation Systems computer-modeling technology. The study was conducted by Pacific Northwest Laboratory and sponsored by the Office of Nuclear Waste Isolation, which is managed by Battelle Memorial Institute for the U.S. Department of Energy. All data used for these simulations were published prior to 1980.	Referenced existing reports.			Composite potentiometric maps are based upon Tanaka et al. (1979). Overall groundwater-flow directions from the Columbia Plateau are toward the Pasco Basin.	Recharge is from throughout the Columbia Plateau wherever precipitation infiltrates the basalt.	Shallow and deep flow systems discharge into the unconfined aquifer and the major rivers within the Pasco Basin.	Two conceptual models were developed. The regional model for the Columbia Plateau consisted of three layers: unconfined aquifer and surface-water bodies, a composite Saddle Mountains/Wanapum layer, and a Grande Ronde layer. The Pasco Basin model had four layers: an unconfined aquifer and surface-water layer, plus three basalt layers corresponding to the Saddle Mountains, Wanapum, and Grande Ronde Basalts. Structural discontinuities were considered important to the overall understanding of groundwater flow.

TABLE 2.1 (cont.)

investigators that the data base was insufficient to allow anything more than very general concepts to be developed.

The first comprehensive site conceptual flow model was presented in the BWIP SCR. In Table 2.2, relevant aspects of this model are tabulated according to the essential flow system components (excluding stimuli) defined in Section 1.0. The SCR model considered Columbia River Basalt to contain intrabasin, intermediate, and interbasin flow systems roughly corresponding to the Saddle Mountains, Wanapum, and Grande Ronde Basalts, respectively. Based primarily on hydrochemical evidence, it was speculated that these systems were more or less hydraulically isolated, although some vertical leakage was thought to occur within anticlinal structures. Major recharge areas were assumed to be located in the outcrop areas of the hydrostratigraphic units, and discharge areas of the deeper units were thought to exist where these units were in direct contact with major rivers. Lateral flow directions for the deeper units were generally to the southeast with essentially no vertical movement (leakage) within the central portion of the Cold Creek syncline. Very low horizontal and vertical hydraulic gradients were thought to exist in deeper units. While heterogeneity in flow interiors was recognized, the SCR model conceptualized these features as having more or less characteristic bulk parameter properties.

Comments in response to the SCR raised by the US NRC and the USGS are presented in Table 2.3. These comments are summarized as follows:

CONCEPTUAL MODEL IN BWIP SITE CHARACTERIZATION REPORT (1982)

(a) Terra Therma interpretation of data.
(b) Rockwell generic value.
(c) Terra Therma considers data or interpretation to be uncertain.

SOURCE AND PURPOSE OF MODEL DEVELOPMENT	HYDROLOGIC FRAMEWORK	PARAMETRIC INFORMATION			BOUNDARY CONDITIONS	RESPONSE	
		Hydraulic Conductivity (m/s)	Storativity	Effective Porosity		Hydraulic Heads	Hydrochemistry
DOE (1982) BWIP Site Characterization Report (SCR). Integrated and evaluated existing data, primarily within the Pasco Basin. Presented a comprehensive conceptual flow model. Conceptual model considered a refinement to Gephart et al (1979). New data included head and hydraulic parameter values measured in approx. 145 test intervals within Columbia River Basalt. Hydraulic parameters based almost exclusively on single borehole tests. Presentation and interpretation of regional and site hydrochemistry.	UNCONFINED AQUIFER Hanford and Ringold Formations comprise an unconfined aquifer system. Lower part of the system (lower Ringold) locally semiconfined. Aquifer thickness of 0 to 60 m. Hanford and middle portion of Ringold the most transmissive units. Paleo stream channel of high transmissivity may exist in Hanford Formation. COLUMBIA RIVER BASALT A layered system. Bedding dips less than 5 degrees within the RRL. Interflows have relatively high permeability. Flow interiors have relatively low permeability. Properties of interbeds do not contrast sharply with interflows. Most groundwater moves horizontally through interflows and interbeds. Minimal quantities move vertically due to confinement provided by flow interiors (c). Increased vertical movement expected to occur in anticlinal areas due to increased fracturing within flow interiors. Flows generally continuous throughout the Pasco Basin. Flows have nearly uniform thickness, but thicknesses of interflows and flow interiors are variable. Groundwater flows under confined conditions. Basalt	UNCONFINED AQUIFER Hanford Fm. 7E-03 to 4E-02 Ringold Fm. E-05 to 8E-04 COLUMBIA RIVER BASALT Flow tops and interbeds: Saddle Mountains E-08 to E-04 (a) Highest values in Priest Rapids. Wanapum E-08 to E-03 (a) Grande Ronde E-10 to E-05 (a) Flow interiors: Horizontal E-14 to E-11 (a) E-04 measured in lower Umtanum. Vertical No tests Model calibration in other areas: a. E-12 to E-10 b. 3E-08	UNCONFINED AQUIFER .01 to .1 COLUMBIA RIVER BASALT Saddle Mountains E-04 to E-03 measured in Priest Rapids interflows. Wanapum No tests (a) E-05 to E-04 (b) Grande Ronde E-05 measured in McCoy Canyon interflow. E-03 to E-06 (b)	UNCONFINED AQUIFER No values COLUMBIA RIVER BASALT Interflows: E-04 to E-01 (b) E-04 measured in McCoy Canyon. (c) Interbeds: No values Flow interiors No values	UNCONFINED AQUIFER Upper boundary is the phreatic surface. Principal natural recharge takes place near outer boundaries by infiltration from ephemeral streams. Natural distributed infiltration within the central part of the Pasco Basin is considered negligible. Significant synthetic recharge has occurred in the 200 West Area, centering at U Pond. Laterally bounded by anticlinal uplands where Hanford and Ringold Formations pinch out. Gable Mountain and Gable Butte form internal boundaries. Columbia River constitutes a regional sink. COLUMBIA RIVER BASALT General Columbia River does not represent a regional groundwater sink for deep basalt units (c). Major discharge into the Columbia River occurs only where basalt units are in direct contact with the river south of the site (c). Yakima Structure has a pronounced effect on hydraulic heads and may be a regional flow boundary. Umtanum Ridge - Gable Mountain anticline may also be a significant hydrologic boundary.	UNCONFINED AQUIFER General flow direction is E from RRL, then E-NE towards Columbia River. Synthetic recharge in vicinity of U Pond has created an extensive groundwater mound with water table rise up to 24 m. Regional lateral gradients topographically controlled. Potential for downward vertical flow into underlying basalt in the 200 West area due to synthetic groundwater mound. Potential for downward vertical flow at Gable Mountain Pond. COLUMBIA RIVER BASALT Saddle Mountains With exception of upper geologic units, general flow directions are NE from Rattlesnake Hills, N towards Gable Mountain/Butte, and SE towards Columbia River (c). Also, S towards Gable Mountain/Butte (c). Downward vertical gradients in western portion of Hanford Reservation. Upward vertical gradients in eastern portion of Reservation. Head drop of 70 m from west to east across Yakima Structure. Wanapum Upper units similar to above (c). Low horizontal and vertical gradients in lower units. Interpreted	UNCONFINED AQUIFER High nitrate plume resulting from waste disposal activities. Shape of plume suggests flow directions from the RRL area to the E and SE. COLUMBIA RIVER BASALT General Longer groundwater residence time with increasing depth. Hydrochemical changes with depth are abrupt, suggesting well defined boundaries between local vs. regional flow systems (c). Also indicates lack of vertical mixing in structurally nondeformed areas (c). Hydrochemical shifts coincident with basalt formation contacts. Suggests that basalt geologic units may also be considered hydrostratigraphic units (c). Grande Ronde (GRB) groundwater appears to be mixing with the Priest Rapids groundwater in the vicinity of Umtanum Ridge - Gable Mountain anticline. Hydrochemistry distribution suggests upward vertical movement of GRB groundwater along structure (c). Saddle Mountains Relatively low TDS, sodium

TABLE 2.2 CONCEPTUAL MODEL IN BWIP SITE CHARACTERIZATION REPORT

formations constitute distinct flow systems (c). A lack of vertical mixing between flow systems, except possibly in anticlinal areas (c). While heterogeneity of interflows and flow interiors is recognized, hydrostratigraphic units are conceptualized as having more or less characteristic bulk properties (c).				Distributed vertical leakage is not considered a major source of recharge/discharge for basalt units (c). Lower boundary undefined. Saddle Mountains (SMB) Lateral boundaries along the edge of the Pasco Basin where SMB outcrops. Recharge occurs in upland areas where SMB outcrops. Discharge believed to be into the Columbia River toward Wallula Gap where outcrop in direct contact with river. Wanapum (WNB) Lateral boundaries exist outside the Pasco Basin where WNB outcrops. Intrabasin recharge in surrounding uplands where WNB outcrops. Interbasin recharge is also thought to occur due to outcrop areas outside the Pasco Basin. Major discharge thought to be into Columbia River towards Wallula Gap and between Sentinal Gap and Priest Rapids dam where WNB in direct contact with river. Discharge by vertical leakage probably occurs along Gable Mountain. Grande Ronde (GRB) Lateral boundaries exist far beyond the Pasco Basin where GRB outcrops. Primarily interbasin recharge from outcrop areas. Some intrabasin recharge may occur where GRB close to ground surface. Major discharge areas similar to WNB. Regional discharge may also occur to Lower Snake River and Columbia River in Columbia River Gorge Region.	regional flow direction is southward (c). May be northward flow component in vicinity of RRL (c). Head drop of 160 m from west to east actross Yakima Structure. Flowing artesian conditions near Columbia River. Grande Ronde Low horizontal and vertical gradients. Interpreted regional flow direction is to the south (c). Potential exists for upward vertical flow into shallower basalt units throughout the Hanford Site.	bicarbonate type. From RRL, TDS increases in a southeasterly direction, possibly indicating a SE direction of flow (c). High nitrates present in some of upper units, suggesting local hydraulic communication with unconfined aquifer. Wanapum Moderate TDS, sodium bicarbonate type. In some locations chloride significant, possibly indicating mixing with GRB groundwater. Significant mixing may occur along Umtanum Ridge - Gable Mountain anticline. Within Cold Creek syncline, primary gas is methane. Outside syncline, primary gas is nitrogen. Grande Ronde Moderate TDS, sodium chloride type, elevated fluoride. Methane dominant gas in RRL area. Less methane in eastern part of Hanford Reservation.

TABLE 2.2 (cont.)

COMMENTS ON BWIP SITE CHARACTERIZATION REPORT

(a) Terra Therma interpretation of data.
(b) Rockwell generic value.
(c) Terra Therma considers data or interpretation to be uncertain.

AGENCY AND REFERENCE GENERAL COMMENTS	HYDROLOGIC FRAMEWORK	PARAMETRIC INFORMATION			BOUNDARY CONDITIONS	RESPONSE	
		Hydraulic Conductivity (m/s)	Storativity	Effective Porosity		Hydraulic Heads	Hydrochemistry
US NRC NRC (1983) Draft Site Characterization Analysis (DSCA) Because of limitations and uncertainties in the data, the conceptual model presented in the SCR cannot be substantiated over other models that equally satisfy the facts. Alternative conceptual models may include: (1) areally continuous layered system with high vertical leakage primarily through intraflow structures, (2) areally discontinuous layered system with high vertical leakage that behaves on the large scale as homogeneous anisotropic system, (3) areally discontinuous layered system bounded by high permeability structures, (4) areally discontinuous system bounded by low permeability structures, and (5) combinations of the above.	COLUMBIA RIVER BASALT Uncertainties regarding the effects that highly variable and complex rock features have on groundwater flow are inadequately addressed. SCR Figure 3-29 (Uatanua outcrop) shows complex, small scale structural and stratigraphic discontinuities that are spaces meters to tens of meters apart. This observation (and others) are not considered in development of DOE's hydrologic framework.	COLUMBIA RIVER BASALT Vertical K within flow interiors has not been measured within the Hanford Site. Test methods provide point measurements in an apparently heterogeneous medium. It is uncertain to what extent these values can be used to predict bulk (large-scale) hydraulic properties. There is a lack of spacial correlation in permeability values obtained from single borehole tests. Based on these data, it is not apparent that characteristic permeability values can be asigned to individual hydrostratigraphic units.		COLUMBIA RIVER BASALT Effective porosity has only been measured at one location.	COLUMBIA RIVER BASALT Boundary conditions are based primarily on heads and/or geometric considerations. Considering the uncertainty of drill-and-test head measurements, many of the proposed hydrologic boundaries are questionable.	COLUMBIA RIVER BASALT Drill-and-test method (using packers) for measuring hydraulic head may be subject to error. Uncertainty in these measurements may be as much as 10 m. Major inconsistencies exist in DOE's assertion that the regional direction of groundwater flow is to the southeast. The apparent low vertical gradients in thick sequences of basalt may in fact indicate a high degree of vertical leakage.	COLUMBIA RIVER BASALT Composition of groundwater along the flow line away from the RRL is not well known. Conclusions regarding separation of groundwater zones based only on hydrochemical data are very speculative. Conclusions regarding vertical mixing (or lack there of) between adjacent formations will be difficult to deduce based on hydrochemical data alone. Carbon-14 ages quoted in the SCR may be much older than actual groundwater ages due to the effects of methanogenesis.
USGS USGS (1983)	COLUMBIA RIVER BASALT The interpretation of minimal vertical leakage across flow interiors in undisturbed layered basalt is subject to question. Although the flux per unit area may be small, the total cross-sectional area available for vertical flow is very large. Many potentially permeable	COLUMBIA RIVER BASALT Large mud losses occured during the drilling of many test holes. Tests conducted in these holes may have been seriously affected by invasion of drilling mud into the formation. Vertically oriented			COLUMBIA RIVER BASALT In other areas of the Columbia Plateau, major anticlines are groundwater divides and represent recharge areas. Major rivers are also flow boundaries and represent areas of discharge. This characteristic is generally independent of the depth of the basalt formation.	COLUMBIA RIVER BASALT The flow system may not be in steady state. Transient stresses may include (1) the groundwater mound developed in the unconfined aquifer, (2) surface water irrigation in the Pasco Basin, (3) groundwater withdrawals in the Pasco Basin, and (4) construction of dams with associated river level changes.	COLUMBIA RIVER BASALT The lateral chemical variations within aquifers cannot be explained by known geochemical reactions. Within the limits of avialable data, it appears that the areal distribution of water types is controled by vertical mixing within the Cold Creek syncline.

TABLE 2.3 NRC AND USGS COMMENTS ON BWIP SITE CHARACTERIZATION REPORT

	features may be vertically oriented. The concept that GRB is an isolated artesian system requires that confined flow occurs over enormous distances and through tightly folded structures. This concept seems unrealistic, particularly if folded structures have increased vertical K. Principal water-bearing zones (interflows) are not necessarily the principal flow paths. In other areas of the Columbia Plateau, flow systems in Columbia River Basalt are considered to be very leaky. Hydraulic connection between the unconfined aquifer and SMB is believed to be spacially continuous, rather than limited to a few specific areas.	features of high permeability (if they exist) will not be readily identified and characterized through the use of single hole tests conducted in vertical boreholes. Interflow hydraulic K's range over 4, 8, and 7 orders of magnitude for the SMB, WMB, and GRB, respectively. It will be difficult to characterize the spacial distribution of K whether for an individual interflow or a formation. Effective K's reported in the SCR are based on a subjective judgement regarding which portion of the interflow is permeable (usually based on porosity). High K intervals may not necessarily coincide with high porosity intervals. The data do not indicate a consistent decrease in K with depth.				In other areas of the Columbia Plateau, the general pattern of groundwater movement appears to be downward in areas of major anticlines and upward in areas of major streams, regardless of the depth of the basalt formation. Increased heads north of Gable Mountain are the effect of irrigation activities north of the Columbia River which began in 1970. The drill-and-test method for obtaining head data is subject to error. Interpretations based on these data are highly uncertain. The anomalously low heads reported in some zones defy explanation. These measurements are probably erroneous.	Conclusions based on stable isotope data cannot be substantiated. Carbon-14 age estimates are erroneous. Hydrochemical data is insufficient and/or of too uncertain quality to support conclusions regarding flow direction, leakage, separation of groundwater systems, etc. At least some hydrochemical properties in SMB are provided by a source external to the formation. Within the WMB, groundwater outside the Cold Creek syncline and inside the syncline show essentially no variation in bicarbonate. The water chemistry in borehole DC-15 is unique. Throughout the Cold Creek syncline, WMB and GRB have essentially identical water chemistry, implying that these formations are hydraulically connected. It is implied that the source of WMB and GRB groundwater is external to the basalts. The most likely source is upward leakage of waters from sedimentary strata underlying the basalt sequence. It is implied that most recharge to SMB occurs in and around the Pasco Basin. Significant chemical variations exist between groundwaters inside and outside the Cold Creek syncline in all three basalt formations. These differences can not be explained by known geochemical reactions.

TABLE 2.3 (cont.)

Major uncertainties existed in the analysis and interpretation of hydrochemical data presented in the SCR. As such, aspects of the conceptual model based on these data were subject to question. This included SCR concepts regarding recharge/discharge areas and the assumed hydraulic isolation between basalt units.

Hydraulic head data based on drill-and-test methods (using packers) may not be representative of actual formation conditions. Thus, flow directions based on these data were open to question.

Hydraulic parameters were based almost exclusively on single borehole tests. These results represent point measurements in apparently heterogeneous media. It was not apparent if these data could be used to assign spacial distributions of bulk parameter values to hydrostratigraphic units.

No direct measurements of the vertical hydraulic conductivity of flow interiors had been made. A knowledge of this parameter was considered critical for understanding regional flow dynamics (particularly vertical leakage).

Uncertainties regarding the effects of heterogeneity within flow interiors were not addressed. There were no data to discount the possible existence of isolated high permeability intraflow features and/or interflow structures.

> The interpretation of minimal vertical leakage on the regional scale was open to question. Although flux rates may be small, the cross-sectional area available for vertical flow is very large.

Gephart et al (1983) refined DOE's concepts regarding the flow dynamics within Columbia River Basalt. As shown in Table 2.4, this model dealt primarily with the hydrologic framework of layered basalt. This was the first model in which DOE specifically recognized the effects of heterogeneity and rock discontinuities on groundwater flow paths. However, the implications of these concepts on regional flow were not addressed. In this model, it was also stated as a probability that the Cold Creek Barrier west of the RRL was an impediment to lateral flow within basalt units.

The most recent comprehensive model to be proposed by DOE was presented in the BWIP Draft Environmental Assessment (DEA) Report. This model was generally consistent with concepts presented in the SCR and refinements provided by Gephart et al (1983). However, it also recognized some of the uncertainties voiced in the SCR comments. Table 2.5 presents those aspects of this model which constitute additions, changes, and/or modifications to the above mentioned documents. The DEA has undergone substantial revisions since it was first issued. It is possible that significant changes to the site conceptual flow model will appear in the Final Environmental Assessment Report.

CONCEPTUAL MODEL AFTER GEPHART et al (1983)

(a) Terra Therma interpretation of data.
(b) Rockwell generic value.
(c) Terra Therma considers data or interpretation to be uncertain.

SOURCE AND PURPOSE OF MODEL DEVELOPMENT	HYDROLOGIC FRAMEWORK	PARAMETRIC INFORMATION			BOUNDARY CONDITIONS	RESPONSE	
		Hydraulic Conductivity (m/s)	Storativity	Effective Porosity		Hydraulic Heads	Hydrochemistry
Gephart et al (1983) Dealt primarily with hydrologic framework. Identification of potential groundwater pathways in Basalt. Emphasis given to identifying stratigraphic and structurally controlled flow paths through which radionuclides might travel from repository. Most data taken from BWIP SCR and earlier reports. First model to specifically recognize effects of heterogeneity and discontinuities within Columbia River Basalt.	COLUMBIA RIVER BASALT Interflows Vesicular and/or brecciated material. Typically comprises 15 percent of flow thickness. May locally comprise up to 50 percent of flow thickness. Flow top forms a more or less continuous layer with variable hydraulic K's Characterized by horizontal flow with relatively high flux rates. Groundwater flow may be channeled into relatively narrow zones (on the order of 1 m) rather than being averaged across entire interflow. Flow Interiors Entablature and colonnade cooling joints may provide flow paths between interflows. Other potential flow paths may occur in vesicular zones, platey zones and zones of localized fracturing. Subhorizontal joints with lengths from 10's to 100's of m have been observed in outcrops. Spiracles of possibly high permeability may extent upward for several meters from flow bottom. Vesicular zone in Cohassett flow interior has been identified in three boreholes. 1 m thick fracture zone of high permeability identified in	COLUMBIA RIVER BASALT Interflows Geometric mean of single borehole tests provides best bulk parameter value for large scale modeling. K's based on total interflow thickness. If flow channelized into narrow feature, actual K of feature greater than values quoted. SMB and WNB: K = E-07 to E-04 with geometric mean of E-05. GRB: K = E-09 to E-05 with geometric mean of E-07. Flow Interiors Horizontal K generally less than E-11 m/s. Based on joint orientation studies, Kv/Kh ratio ranges from 2 to 3.5. Cohassett vesicular zone measured in three boreholes had K ranging from E-13 to E-08 m/s. Umtanum fracture zone had K = E-04 m/s.		COLUMBIA RIVER BASALT Most fractures filled with secondary minerals. Volume of unfilled fractures estimated to be less than 0.004	COLUMBIA RIVER BASALT Yakima Structure is probably an impediment to lateral groundwater flow.	COLUMBIA RIVER BASALT Low vertical gradients indicate that flow directions are mainly horizontal (c). In structurally nondeformed areas, lateral flow is mainly in the direction of regional dip (c).	COLUMBIA RIVER BASALT Deep groundwater may be moving vertically upward to mix with shallower water in vicinity of the Yakima Structure.

TABLE 2.4 MODIFICATIONS TO SITE CONCEPTUAL MODEL BY GEPHART ET AL (1983)

	lower Umtanum flow interior. Structural Discontinuities Cold Creek syncline may have strike-slip faults that cut multiple flows. Lateral extent of features up to perhaps 10 km. Tectonic breccias with thicknesses on the order of 1 m observed in boreholes and outcrops. Yakima Structure may be example of feature which impeads lateral groundwater flow. 5 m thick tectonic breccia identified in Frenchman Springs within RRL did not have high K.						

TABLE 2.4 (cont.)

TABLE 2.5 CONCEPTUAL MODEL PRESENTED IN BWIP ENVIRONMENTAL ASSESSMENT (1984)

(a) Terra Therma interpretation of data.
(b) Rockwell generic value.
(c) Terra Therma considers data or interpretation to be uncertain.

SOURCE AND PURPOSE OF MODEL	HYDROLOGIC FRAMEWORK	PARAMETRIC INFORMATION			BOUNDARY CONDITIONS	RESPONSE	
		Hydraulic Conductivity (m/s)	Storativity	Effective Porosity		Hydraulic Heads	Hydrochemistry
DOE (1984) BWIP Draft Environmental Assessment. Conceptual model generally follows BWIP SCR and Gephart (1983). This table contains only additions, changes, and/or significant modifications to the above mentioned documents.	UNCONFINED AQUIFER Unconfined aquifer is thickest (75 m) along the eastern edge of the RRL. COLUMBIA RIVER BASALT It is recognized that over a broad region, vertical leakage (even across low K flow interiors) can be an important consideration. Flow concepts specify very little leakage across flow interiors in structurally nondeformed areas (c). Pillow basalts and spiracles have not been identified in any boreholes. However, their existence should be anticipated, based on outcrop observations. These features of possibly high permeability may locally influence groundwater movement.	UNCONFINED AQUIFER K ranges from E-03 to E-02 for coarse sands and gravels and as low as E-07 for finer grained indurated sediments. COLUMBIA RIVER BASALT Interflows Uncertainty of K values determined by tests conducted in interflows and interbeds is estimated to be a factor of 2X or 3X. Flow Interiors Results of an initial ratio test conducted in the Rocky Coulee flow interior suggest a vertical K equal to E-10. Since this is the first test of this type, an uncertainty cannot be asigned to this value (c). It is believed that the vertical K of flow interiors will likely be similar to the horizontal K values currently reported. For tests conducted in flow interiors, reported K values.		COLUMBIA RIVER BASALT Re-analysis of tracer test in McCoy Canyon flow top gave an effective thickness range of 2E-03 to 3E-03 m. Based on an effective test interval thickness of 11 m (a), this results in an effective porosity ranging from 1.3E-04 to 2.7E-04.	COLUMBIA RIVER BASALT Regional recharge to deep basalts is thought to result from a combination of (1) interbasin groundwater movement, (2) leakage across structural and stratigraphic discontinuities, and (3) leakage across nondeformed flow interiors. Significance of each factor depends on the location. Groundwater from shallow basalt probably discharges by leakage to the unconfined aquifer and ultimately to the Columbia River. Umtanum Ridge - Gable Mountain anticline may form a hydraulic boundary of low lateral hydraulic conductivity. This feature may also be an area of increased vertical leakage between deep and shallow groundwater.	UNCONFINED AQUIFER In the central part of RRL, water table is approx. 50 meters below ground surface. COLUMBIA RIVER BASALT Overall flow patterns roughly conform to bedrock dip (c). Within the Cold Creek syncline, hydraulic head changes in deep basalts appear to be slow and of small magnitude. Head variations in shallow basalts tend to be more rapid and have larger magnitudes. East of the Yakima Structure, environmental head changes over several years have generally been less than 2 m. West of the structure, heads have declined up to 12 m due to heavy groundwater withdrawls. In the western part of the site, areas close to Rattlesnake Hills, Yakima Ridge, and Umtanum Ridge, have downward vertical gradients in shallow basalt (c). Eastward across the site, heads become more uniform with depth in the central Cold Creek syncline. Near the Columbia River, vertical gradients in shallow basalt are either upward or variable (c).	UNCONFINED AQUIFER COLUMBIA RIVER BASALT Pronounced shifts in hydrochemistry with depth have been observed in some boreholes. The stratigraphic horizons associated with these shifts vary with location.

TABLE 2.5 CONCEPTUAL MODEL PRESENTED IN BWIP DRAFT ENVIRONMENTAL ASSESSMENT

		have a tendency to be overestimates.				In deep basalt, vertical gradients are generally negligible or slightly upward (c). If observed low vertical gradients have been maintained in the geologic past, vertical groundwater movement and mixing has been very slow (c).	

TABLE 2.5 (cont.)

Finally, in Table 2.6 are some additional aspects of BWIP site conceptual models developed by Terra Therma from recent data. These include hydraulic head data obtained from permanent piezometer completions in vicinity of the RRL, responses in those installations observed during the drilling of other boreholes, and more recent hydrochemistry data. As new data become available and additional analyses are performed, Table 2.6 will be continually revised and updated by Terra Therma.

TABLE 2.6 TERRA THERMA INTERPRETATIONS OF RECENT DATA

(a) Terra Therma interpretation of data.
(b) Rockwell generic value.
(c) Terra Therma considers data or interpretation to be uncertain.

SOURCE	HYDROLOGIC FRAMEWORK	PARAMETRIC INFORMATION			BOUNDARY CONDITIONS	RESPONSE	
		Hydraulic Conductivity (m/s)	Storativity	Effective Porosity		Hydraulic Heads	Hydrochemistry
TERRA THERMA DATABASE						Significant hydraulic responses due to drilling activities have been observed in observation wells. Hydraulic head changes have ranged from .06 to 1.8 m. Responses have been observed from .64 to 9. km away from the drilling activities. In vicinity of the RRL, lateral flow direction in the Mabton interbed is to the west. In vicinity of the RRL, significant downward vertical gradients exist in SMB. In vicinity of the RRL, very low horizontal gradients exist in WMB and GRB. In vicinity of the RRL, very low vertical gradients exist in WMB and GRB. The vertical direction of flow is interpreted to be upward. Natural head variations in Columbia River Basalt appear to br slow and have small magnitudes. Low vertical and horizontal gradients seem to be characteristic of WMB and GRB throughout the Cold Creek syncline.	Nitrate contamination exists in both the unconfined aquifer and the uppermost sedimentary interbeds of the SMB (related to the waste water disposal at the 200 West Area. The nitrate plume suggest groundwater flow to the east and southeast in this aquifer. High gas content/high methane zone in vicinity of RRL contrasts with low gas content/high nitrogen in other areas of Pasco Basin. Origin of methane is uncertain, but upward movement of fluids is possible. Possible upward flow and mixing of waters from GRB in the lower WMB in vicinity of the RRL. There is chemical evidence for mixing of waters along Umtanum Ridge-Gable Mountain Anticline and perhaps along Benson Ranch Syncline. Waters NW of the Cold Creek Barrier are chemically distinct from waters in the RRL.

TABLE 2.6 TERRA THERMA INTERPRETATIONS OF RECENT DATA

TABLE 2.6 TERRA THERMA INTERPRETATIONS OF RECENT DATA

3.0 REGULATORY FRAMEWORK

In Section 1.0 above, Terra Therma Inc. defines "Conceptual Models" in terms of the need to "determine the relevant behavior of the system". In order to apply this definition of conceptual models, it must be possible to identify relevant behavior (or behaviors, as the conditions of concern may vary). It is the position of Terra Therma that for the purposes of hydrogeologic reviews conducted by the NRC staff, relevance can be established only with reference to the regulations that the staff are directed to apply, that is, 10 CFR Part 60 and 40 CFR Part 191. The purpose of this section is to identify the relevant portions of these regulations and to develop a regulatory framework that will permit the staff and its technical assistance contractors to determine relevant hydrogeologic behavior. We consider that this is a necessary step in formulating and constraining conceptual models at BWIP or at any other site.

3.1 NATURE OF THE TECHNICAL REGULATIONS

3.1.1 Subpart E, 10 CFR Part 60

Principal portions of Subpart E of 10 CFR Part 60 that require technical assessment include:

(1) Through Permanent Closure

60.111(a), limiting radiation exposures and releases of radioactive material during operations.

60.111(b), requiring the option of waste retrieval be preserved during operations.

(2) After Permanent Closure

60.112, limiting releases of radioactive materials to the accessible environment (also limiting radiation exposures and concentrations of radionuclides in special sources of groundwaters) after permanent closure to those permitted by the EPA standard (40 CFR Part 191).

60.113(a)(1)(ii)(A), requiring a minimum waste package containment time.

60.113(a)(1)(ii)(B), limiting the radionuclide release rate from the engineered barrier system.

60.113(a)(2), addressing minimum pre-emplacement groundwater travel time from the disturbed zone to the accessible environment.

60.122, addressing favorable and potentially adverse siting conditions.

60.131 - 60.135, addressing design criteria.

For each of the post-closure subsystem performance objectives (i.e., waste package containment, release rate from the engineered barriers, and re-emplacement groundwater travel time), the final rule provides for flexibility in the regulation by permitting DOE to propose and the Commission to accept a lower subsystem performance goal provided that DOE can demonstrate with reasonable assurance that the overall system meets the EPA standard.

3.1.2 The EPA Standard

Section 112 of 10 CFR Part 60 requires DOE to demonstrate that the applicable EPA Standard will be met for the overall repository system performance. Subpart B of 40 CFR Part 191 establishes several different types of requirements:

191.13, limiting cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal.

191.14, describing qualitative assurance requirements.

191.15, limiting radiation doses to individuals for 1,000 years after disposal for cases of undisturbed performance.

191.16, limiting the radionuclide concentrations in special sources of groundwater for 1,000 years after disposal for cases of undisturbed performance.

For definitions of terms and discussion of the details of 40 CFR Part 191, consult Federal Register, v. 50 no. 181, Thursday Sept. 19, 1985, p. 38066-38089. For discussion of the NRC staff position on the applicability of the EPA standard to NRC licensing reviews, consult Draft Generic Technical Position on Licensing Assessment Methodology, April 30, 1984.

3.2 RELEVANT HYDROGEOLOGIC BEHAVIOR IN A REGULATORY FRAMEWORK

3.2.1 Subsystem Performance

In order to determine the need for conceptual models to assess hydrogeology with respect to the subsystem performance of a geologic repository, it must be possible to show that groundwater flow could qualitatively affect the performance of the subsystem under conditions that are appropriate to the subsystem performance objective.

3.2.1.1 Through Permanent Closure

Because the design basis for an operational repository is anticipated to include an essentially dry opening, the only apparent method for groundwater transport of radionuclides in quantities that might exceed the 10 CFR Part 20 limits would be in the event of a flooding of the mined opening. Thus, it appears that the limit of hydrogeologic concern with respect to 60.111(a) would be the consideration of mine-water inflows during operation (as opposed to during the construction of the repository, at which time there would be no radionuclides in place).

Similarly, the apparent limit of hydrogeologic concern with respect to retrievability would be to assess water inflows during operation as they might affect the ability to retrieve waste.

3.2.1.2 After Permanent Closure

Waste Package and EBS

With respect to hydrogeology, the assessments of waste package containment and release rate from the engineered barrier system require information on anticipated water inflows to and through the engineered barrier system and its components for a time frame of up to 1,000 years after permanent closure.

GWTT

The pre-emplacement groundwater travel time (GWTT) requirement addresses groundwater flow from the edge of the disturbed zone to the accessible environment along paths of likely radionuclide transport, assuming that the structural framework, hydraulic parameters, and boundary conditions of the system are those that existed at the site before any significant human-induced stresses. The concepts of the Disturbed Zone and approaches to dealing with groundwater travel time are addressed in detail in two NRC Draft Generic Technical Positions:

> Draft Generic Technical Position: Interpretation and Identification of the Extent of the Disturbed Zone in the High-Level Nuclear Waste Rule (10 CFR 60), by M. Gordon et al., May, 1985.

Draft Generic Technical Position on Groundwater Travel Time (GWTT), by R. Codell, undated DUP 7 (received by NWC on November 19, 1985).

Nuclear Waste Consultants has provided extensive comment on these NRC staff documents (NWC Communication No. 7, December 13, 1985).

The assessment of GWTT will require information on the following hydrogeologic matters:

The pre-waste emplacement physical environment and its potential spatial and short-term temporal variabilities.

The paths of likely radionuclide travel.

Travel times along the likely paths of radionuclide travel from the disturbed zone to the accessible environment.

Note that because the GWTT performance objective is restricted to the performance of an hypothetical, inert, non-decaying, non-adsorbing tracer, there is no need to address chemical properties of the system between the disturbed zone and the accessible environment.

EPA Standard

Because it is generally agreed that groundwater is the most likely medium by which significant quantities of radionuclides could escape a repository under post-emplacement conditions, evaluation of compliance with the EPA Standard will require assessment of conditions and parameters that can control the flux of radionuclides across the boundaries that are specified or implied in 40 CFR 191.13, 191.15 and 191.16. (For the purposes of this discussion, it is assumed that compliance with the dose limitations of 191.15 can be assessed from the cumulative fluxes of radionuclides and a characterization of pathways that derives from the framework analysis of the site.)

Because the EPA Standard is a flux-based performance objective that applies over times of up to 10,000 years, assessments will require information that addresses the following hydrogeologic matters:

> The source term for radionuclide releases from the accessible environment.
>
> Those aspects of the post-emplacement physical and chemical environments that can control flux of radionuclides, including the potential spatial and temporal variabilities of the environment.
>
> Flow paths from the repository to the accessible environment.
>
> Cumulative releases of radionuclides across the relevant boundaries that are specified in 40 CFR 191.

3.3 IMPLICATIONS FOR CONCEPTUAL MODELS

3.3.1 Types of Relevant Behavior

Based on this analysis of regulatory framework, it appears that there are three basic styles of relevant behavior:

1. Mass flux of groundwater. Mass flux of groundwater is needed to address aspects of operational safety, retrievability, waste package performance, and releases from the Engineered Barrier System (EBS).

2. Groundwater travel time. Groundwater travel time is needed only for pre-emplacement conditions and for the limited purpose of addressing the GWTT performance objective.

3. Radionuclide flux in the groundwater system. Radionuclide flux across boundaries specified or implied in 40 CFR Part 191 is needed to address the EPA Standard. Additionally, radionuclide flux within the EBS is relevant to the assessment of the release rate from the EBS.

3.3.2 Scales

Based on this analysis of regulatory constraints, it appears that three scales of spatial and three scales of temporal concerns need to be considered in conceptual models that address the hydrologic aspects of 10 CFR Part 60 and 40 CFR Part 191:

1. Models at the scale of the performance of single canister emplacement. This scale would be needed to address the mass flux of groundwater past canisters for 300 - 1000 years in order to evaluate the waste package performance objective.

2. Models at the scale of performance of the operational repository. This scale would be needed to address mine-water inflow (mass flux) as it might affect the operational functions of the repository that are important to safety and as it might affect the ability to retrieve waste.

3. Models at the scale of the performance of the Engineered Barrier System. This scale would be needed to assess mass flux of groundwater into the EBS and radionuclide flux within the EBS in order to evaluate the performance objective for release rate from the EBS. Note that there may be little or no difference in spatial scale between case 2 and case 3, but the temporal scale for the evaluation of the EBS is 300 - 1000 years, versus the temporal scale of approximately 50 years for the operational and retrieval requirements.

4. Models of the physical flow system at a scale of the distance from the Disturbed Zone to the Accessible Environment to address the pre-emplacement groundwater travel-time objective. These models are independent of time in the sense that they must be capable of addressing the required performance (travel time of an inert, non-decaying, non-adsorbing tracer) at any time scale.

5. Models of the overall geologic repository system (which includes the EBS, see 10 CFR 60.2) at the scale of the distance from the repository to the accessible environment to address the cumulative

releases of radionuclides across boundaries described or implied in 40 CFR Part 191. These models are independent of time in the sense that they must be capable of addressing the required performance at any time scale.

For the purposes of this initial report on evaluation of conceptual models for BWIP, Terra Therma will limit discussion that follow to consideration of conceptual models at the scales of repository performance, to address the GWTT and EPA Standard performance objective. As directed by the NRC project Officer, Terra Therma will address conceptual models at other performance scales in the scheduled updates of this report.

4.0 DESCRIPTION OF BWIP SITE DATA

4.1 INTRODUCTION

Using the categories presented in Section 1.0 (framework, parametric data, boundary conditions, stimuli, and response), the various data available for the BWIP site are used to provide the overall basis for a conceptual model. In this section, a brief discussion of each data-set is presented from the viewpoint of a qualitative analysis of the available data. The full data base is not included in this document, since a Database Update will be prepared and submitted in the near future and all analyses of the data will occur during preparation of the Subtask 2.5 report.

4.2 FRAMEWORK

4.2.1 Introduction

Although all components of the conceptual model are critical to the development of a successful model, the framework is particularly important since it provides the foundation for the model. Since the framework is the rigid structure within which the various processes occur, it is the logical starting point for any conceptual model. At BWIP, a considerable amount of geologic data has been collected from both the surface and subsurface. A relatively consistent description of the stratigraphy and structure has evolved at BWIP, making the framework the least controversial of all the model components. The following sections summarize the framework, based on available data.

4.2.2 Regional Geology

4.2.2.1 Location

The Reference Repository Location (RRL) is in DOE's Hanford Reservation near Richland, Washington. The RRL is in the central portion of the Cold Creek syncline within the Pasco Basin, a structural and topographic basin located within the Columbia Plateau (Figure 4.1).

Major surface features of significance in the area include:

> The Columbia River, Umtanum Ridge, Gable Butte, and Gable Mountain to the north;
>
> Yakima Ridge to the west;
>
> Rattlesnake Mountains to the south;
>
> The Columbia River to the east and Yakima River to the southeast (Figure 4.2).

FIGURE 4.1 LOCATION OF THE HANFORD SITE

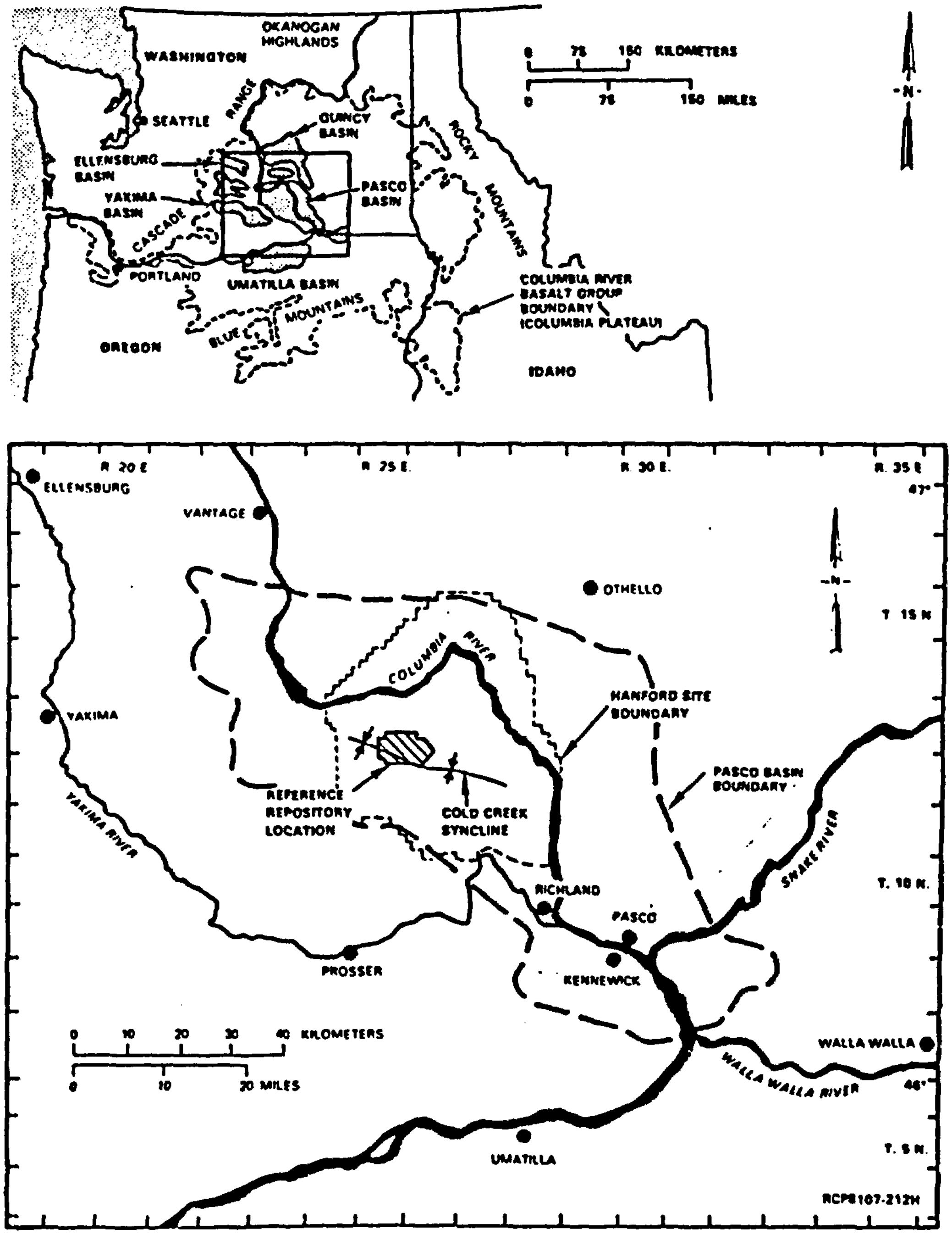
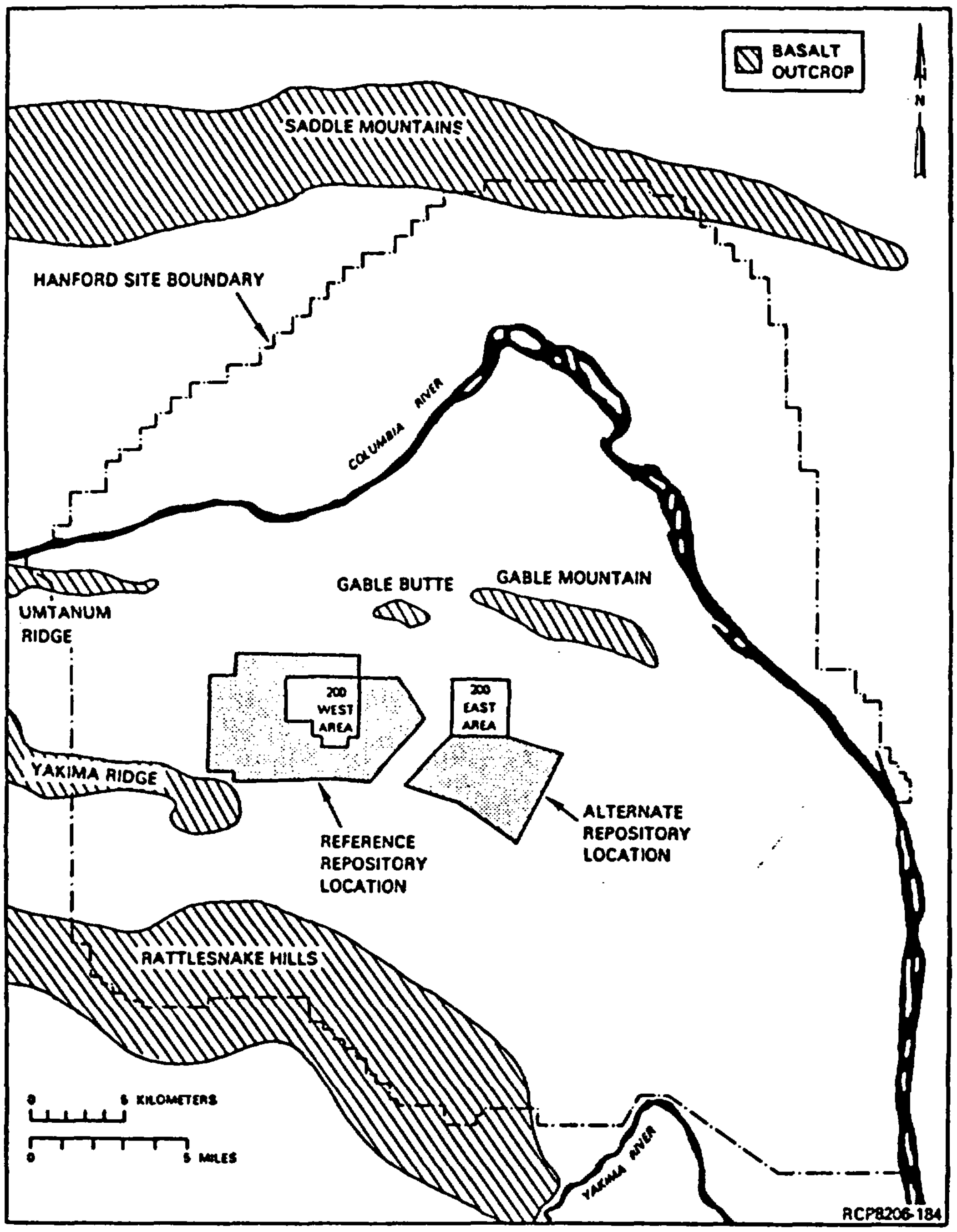


FIGURE 4.2 LOCATION OF THE REFERENCE REPOSITORY LOCATION



4.2.2.2 General Geology

The Columbia Plateau coincides with the distribution of Miocene flood basalts of the Columbia River Basalt Group. The Plateau is a large structural and topographic depression, with its low point near the location of the RRL. The maximum thickness of the Columbia River Basalt Group, including its interbedded sediments, is approximately 5,000 meters (Mitchell and Bergstrom, 1983). The flood basalts, underlain by metamorphosed sedimentary and volcanic units, were erupted from a series of north-northwest-trending linear vents (Waters, 1961). Individual flows range in thickness from a few centimeters to approximately 100 meters, with most flows between 20 and 40 meters thick. The basic waste disposal concept for the Hanford site is that the HLW would be placed in a repository that would be excavated within the dense interior of one of the Columbia River Basalt flows.

The Columbia River Basalt Group has been divided into 5 formations and 19 members (Swanson et al, 1979; Camp, 1981) (Figure 4.3). The areal distribution of the Columbia River Basalt Group is shown on Figure 4.4. Because the Imnaha and Picture Gorge Basalts do not crop out in the area of interest, they will not be discussed further.

FIGURE 4.3 STRATIGRAPHIC NOMENCLATURE FOR THE COLUMBIA RIVER BASALT GROUP

(after Swanson et al, 1979)

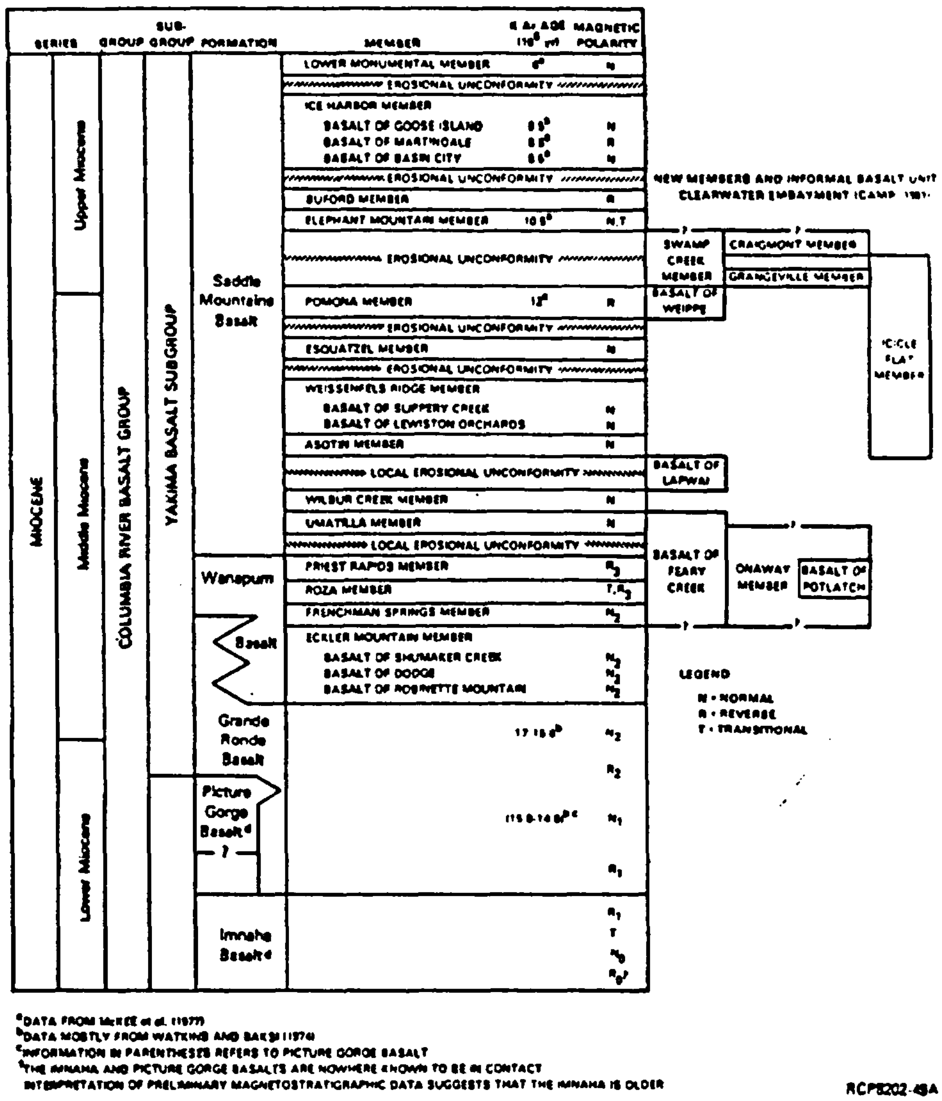
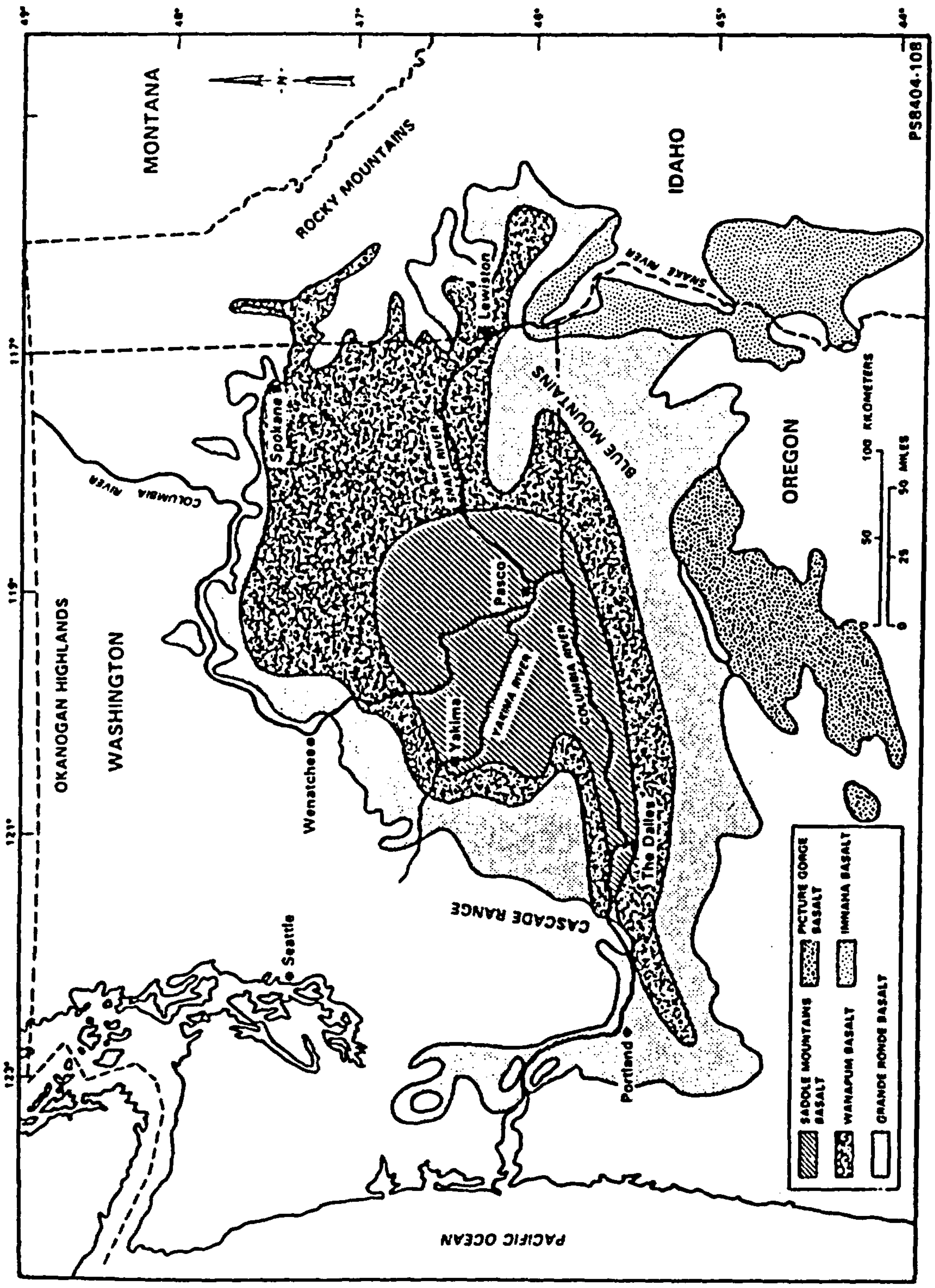


FIGURE 4.4 DISTRIBUTION OF COLUMBIA RIVER BASALT GROUP

(after Wright et al, 1973)



The Grande Ronde Basalt, extruded 17 to 15.6 million years before present (mybp), is the most areally extensive and voluminous of the Columbia River Basalt Group. The known thickness ranges from tens of meters along the Plateau margins to over 1,000 meters in the Pasco Basin. The only regional (i.e., at the scale of the Plateau) subdivisions are four magnetostratigraphic units, indicated on Figure 4.3. However, at a subregional scale, there are a number of "through-running" flows that extend over areas of at least 250 square kilometers (Long and Landon, 1981). Two of these through-running flows within the Pasco Basin are currently being considered as candidate horizons for the geologic repository.

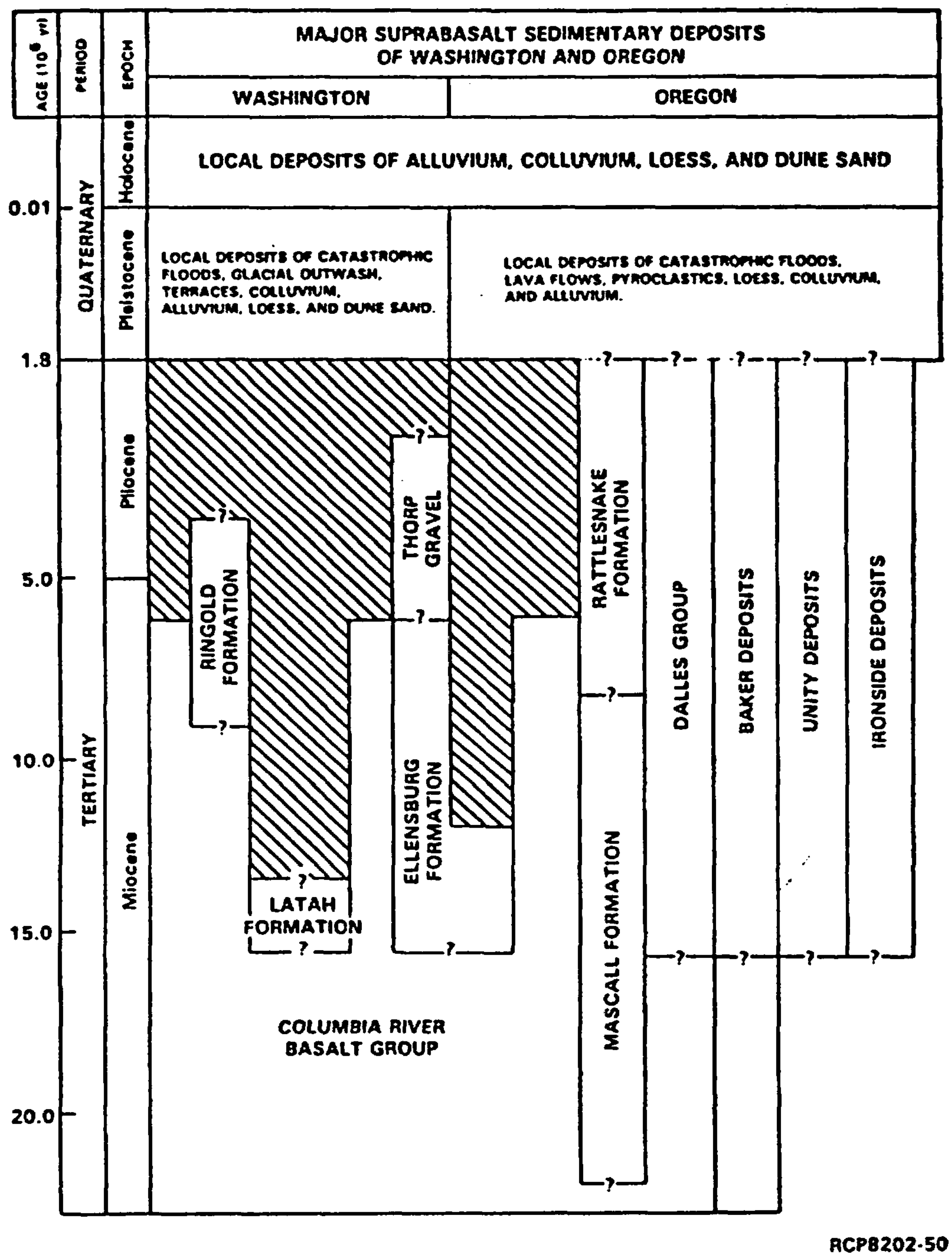
The Grande Ronde Basalt is overlain by the Wanapum Basalt, extruded 14 to 13.5 mybp. The Wanapum Basalt has been subdivided into four recognized members regionally (Figure 4.3).

The youngest formation of the Columbia River Basalt Group is the Saddle Mountains Basalt, which has been divided into at least 10 members (Figure 4.3). The extrusion period, 13.5 to 6 mybp, was characterized by declining volcanism, the deposition of interbedded sediments (Ellensburg Formation), tectonic folding and canyon cutting.

The stratigraphy of the suprabasalt sedimentary formations is shown in Figure 4.5. The Ellensburg Formation is primarily weakly lithified clastic and volcanoclastic sediments derived from the Cascades. Units of the Ellensburg Formation are interbedded with and overlie Wanapum and Saddle Mountains Basalts. Fluvial deposits of the Mio-Pliocene Ringold Formation overlie the Columbia River Basalt Group. Pleistocene and Holocene Hanford Formation deposits of alluvium, colluvium, eolian loess overlie Ringold sediments.

The Cold Creek syncline is one of a series of eastward-trending folds that comprise the Yakima Fold Belt. The anticlines in the fold belt are typically narrow, linear and somewhat asymmetrical; the synclines are typically broader than the anticlines. The ridges, buttes and mountains listed in Section 2.1 are the surface expression of the anticlines adjacent to the Cold Creek syncline. Major faults are generally associated with the anticlines. Fault plane solutions for shallow swarm earthquakes suggest that reverse faults are parallel to the axial planes of the anticlines. Conjugate strike-slip faults are also thought to exist within the limbs of the folds. A generalized structure cross section is presented in Figure 4.6.

FIGURE 4.5 GENERAL STRATIGRAPHIC RELATIONSHIP OF SUPRABASALT SEDIMENTS



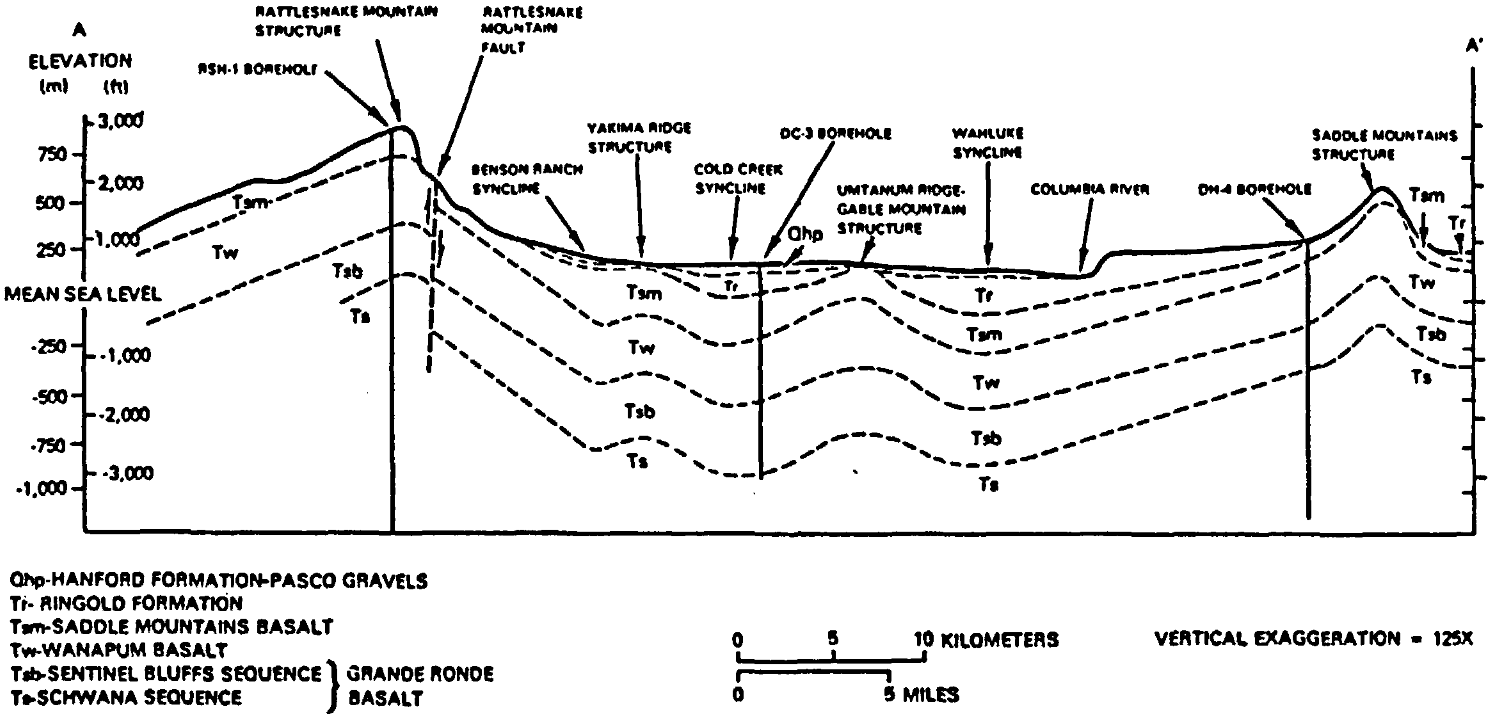


FIGURE 4.6 GENERALIZED STRUCTURAL CROSS SECTION

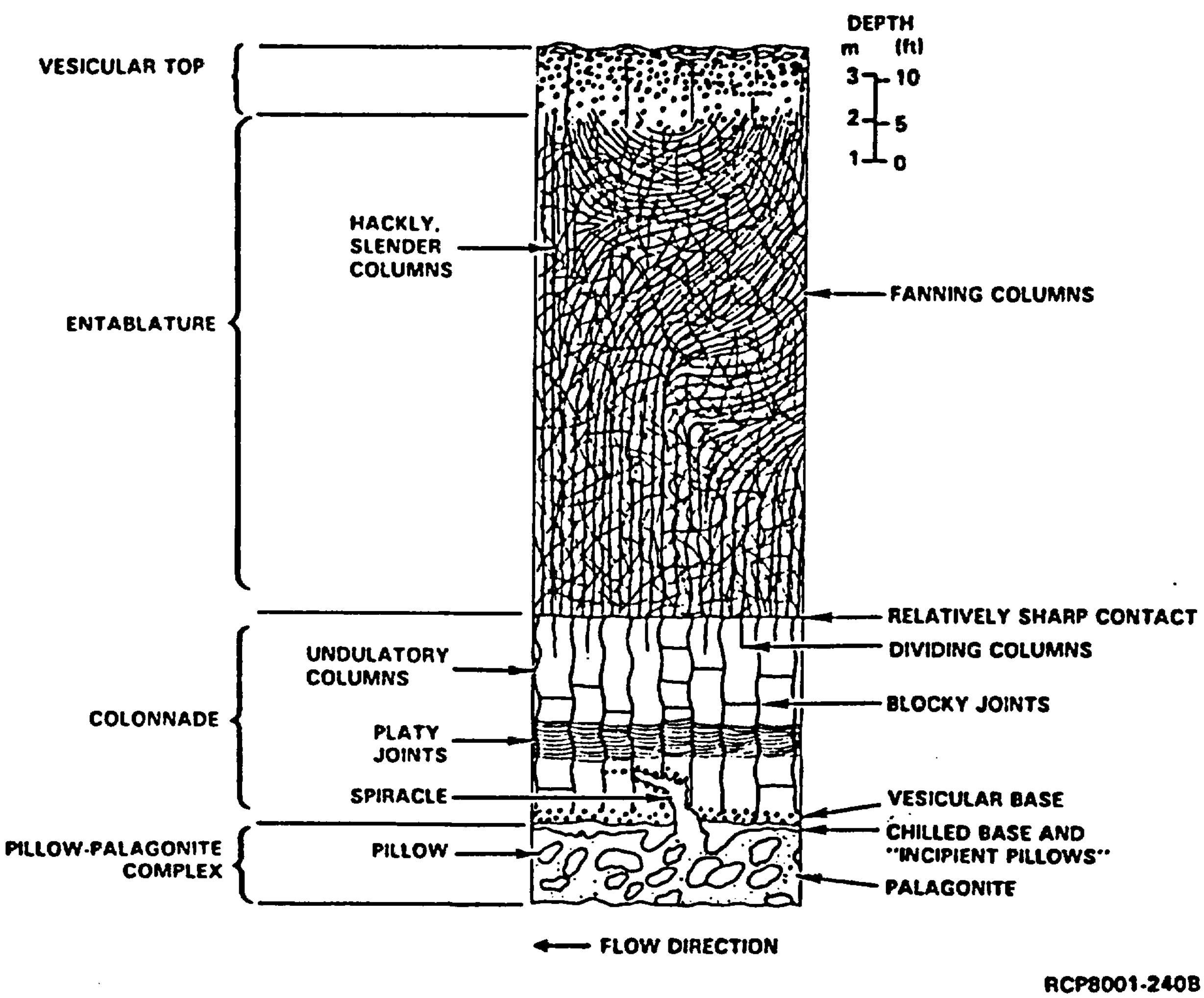
Internal structures that formed during the emplacement and subsequent cooling of the lava are termed "intraflow structures" (DOE, 1984). Particularly important are the cooling joints that produce polygonal columns or hackly blocks. In general, three major intraflow structures are recognized: vesicular or brecciated flow tops; irregular and discontinuously jointed entablature near the middle of a flow; and more regularly jointed colonnade near the bottom of the flow (Figure 4.7). The base of a flow is typically a thin (approximately 0.5 meter) zone of fractured, glassy basalt. The three major intraflow structures may vary in thickness, be absent in a given flow, or occur repeatedly within a single flow. The orientation of joints and fractures is typically nearly vertical, but occasionally approach horizontal. Radiating columnar joints have been observed in surface exposures of basalt flows. Limited core data indicate secondary mineralization in fractures.

4.2.2.3 Significant Basalt Flow Characteristics

A typical flow is composed of an upper brecciated and/or vesicular flow top overlying a more dense flow interior, which in turn overlies a thin basal zone of glassy basalt with some rubble. Basalt interflows comprise the flow top and bottom of two adjacent flows and may include a sedimentary interbed. These features typically represent 15 percent of the basalt flow but may locally exceed 50 percent (e.g., Umtanum flow top at RRL-2).

FIGURE 4.7 GENERALIZED CROSS SECTION OF INDIVIDUAL BASALT FLOW

(after Swanson and Wright, 1976)



Basalt flow interiors, existing between interflow zones, are characterized by reduced open fracturing. The features are thus considered to control vertical flow (leakage) between adjacent interflow zones. Flow interiors are generally characterized by colonnade and entablature jointing with a preferred vertical orientation. However, a variety of internal structures, generally related to the pattern and density of fracturing, have been observed within boreholes and along surface outcrops. These structures include vesicular zones, platy zones, fanning entablature, spiracles, breccia, sub-horizontal pervasive fractures, and flow top/interior thickness irregularities.

4.3 PARAMETRIC DATA

At BWIP, available hydraulic data include permeability values derived from numerous single-borehole tests. Although a few multi-borehole tests of limited scale have been performed, bulk values of permeability and storativity which can be assigned to the Columbia River Basalt as a whole are not available. A single tracer test which was run in the McCoy Canyon has provided an estimate of porosity, but questions regarding the validity of the test conditions suggest the porosity value cannot be related to the Columbia River Basalt in general.

Hydrologic testing conducted by RHO has indicated that basalt interflows have relatively high permeability and thus are considered to control horizontal groundwater flow within the BWIP site. Measured transmissivities, based on single-borehole tests, range over 9 orders of magnitude from E-10 to E-01

m^2/s. Commonly, the lateral variability within an individual interflow is comparable to that between interflows. Single borehole testing provides spot measurements of hydraulic properties integrated over a very small area. These tests have thus indicated that basalt interflows are extremely heterogeneous on the small scale. It is currently unknown if bulk parameter values (e.g., geometric mean values of transmissivity) can be assigned to interflows for performance modeling at the repository scale.

A limited number of single borehole tests have been conducted within flow interiors. The majority of these tests have indicated extremely low hydraulic conductivity ranging between E-14 to E-10 m/s. Two of the tests, however, measured substantially higher hydraulic conductivities ranging from E-08 to as high as E-03 m/s. This could be interpreted to mean that while most dense basalt within flow interiors has very low hydraulic conductivity, rather isolated inhomogeneities with much higher conductivity could potentially exist. If isolated high permeability "windows" exist within the flow interiors, vertical leakage and transport at the repository scale might be dominated by the properties of these anomalous structures. Existing data is not sufficient to estimate distribution, frequency, and hydraulic characteristics of these possible "windows". However, as described in Section 6.1.1, a sensitivity analysis might indicate what data, if any, is essential for accurate modeling of the BWIP system.

4.4 BOUNDARY CONDITIONS

Only one potential hydraulic boundary has been identified directly from data collected at the BWIP site. The Cold Creek Barrier has been defined on the basis of hydraulic head data in the vicinity of the structure. Although the exact nature of the structure is not known, head differences of 70 meters in the Saddle Mountains Basalt and 160 meters in the Wanapum Basalt have been observed on opposite sides of the structure. Testing has not been performed to investigate stress responses across the structure.

Other boundaries that have been suggested include the outcrop area of the Columbia River Basalts, the Columbia River, miscellaneous faults, and anticlines. Direct evidence is not available to further define the potential role of these features in the performance of the BWIP site. An effective lower boundary for the BWIP Hydrologic System has not been defined with respect to performance assessment of the site.

4.5 RESPONSES

4.5.1 Hydraulic Gradients

Any conceptual model which successfully "simulates" the groundwater system at BWIP must consider the low vertical and horizontal gradients that have been observed in Wanapum and Grande Ronde Basalt. With the recent installation of high quality piezometers, it has become apparent that the lateral and vertical head variations in deeper basalt units are comparable to the uncertainty in the methods available for their measurement. Although calculated gradients may always retain some uncertainty, upper limits can be defined and used in any modelling effort.

Fluid injection and withdrawal associated with drilling activities on the BWIP site have resulted in significant responses in the hydraulic head at various monitoring locations. Hydrographs presented at the DOE-NRC workshop (December, 1985) indicate that lost circulation of drilling fluid and well development have resulted in water level increases and decreases over considerable distances (Refer to Table 4.1 for summary of observed affects). These responses range from less than .1 meters to nearly 2 meters of change and have been observed up to 9.7 kilometers from the drilling/development activity.

4.5.2 Hydrochemistry

As is the case with the low hydraulic gradients at BWIP, conceptual models that successfully "simulate" the groundwater system of the Pasco Basin must be consistent with significant aspects of the hydrochemistry of the system. The inherent problem with this approach is it's difficulty in developing a technical consensus as to what hydrochemical data are significant with respect to describing the groundwater flow system.

TABLE 4.1 OBSERVED HYDROLOGIC RESPONSES DUE TO DRILLING/COMPLETION ACTIVITIES

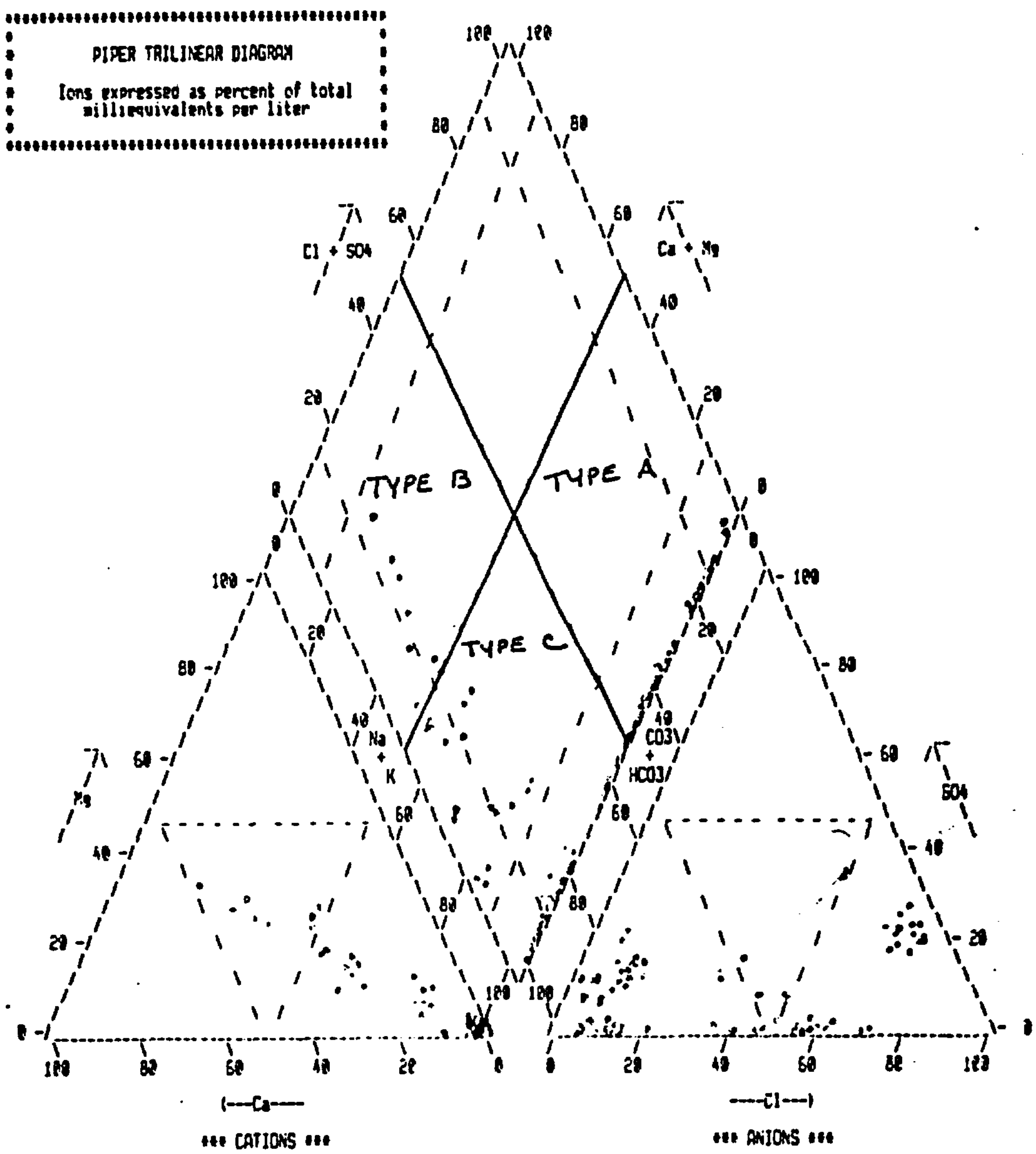
ACTIVITY			OBSERVED CHANGES			
BOREHOLE NUMBER	ACTIVITY	ZONE OF FLUID LOSS OR GAIN	WELL INFLUENCED	DISTANCE * FROM ACTIVITY	UNIT AFFECTED	MAXIMUM AFFECT **
RRL-2C	DRILLING	UNCF/SM/WANP				
	DRILLING	GR 5 FLOW TOP				
RRL-2B	DRILLING	SAD MTS/WANAP				
	DRILLING	RC FLOW TOP	RRL-2A		RC FLOW TOP	2.3
	DRILLING	RC FLOW TOP	RRL-2C		RC FLOW TOP	69.3
RRL-14	BRID PLG REM	COMP GRD RONDE	DC-22C	2100	COHASSETT FT	3.8
	BRID PLG REM	COMP GRD RONDE	DC-22C	2100	UMTANUM FT	2.0
	BRID PLG REM	COMP GRD RONDE	DC-20C	13500	ROCKY COU FT	.8
	BRID PLG REM	COMP GRD RONDE	DC-20C	13500	COHASSETT FT	.7
	BRID PLG REM	COMP GRD RONDE	DC-20C	13500	UMTANUM FT	.5
RRL-17	DRILLING	COHAS FT/GR5 FT	RRL-2C	5300	COHASSETT FT	1.5
	DRILLING	COHAS FT/GR5 FT	DC-20C	4000	COHASSETT FT	1.0
DC-23W	DRILLING	UNCONFINED				
	DRILLING	PRIEST RAPIDS	DC-20C	11400	PRIEST RAPIDS	.2
	DRILLING	ROZA	DC-20C	11400	PRIEST RAPIDS	.5
	DRILLING	SENT GAP/GINK	DC-20C	11400	PRIEST RAPIDS	2.3
	AIR-LIFT DEV	COMPOSITE WANP	DC-20C	11400	PRIEST RAPIDS	-2.1
	DRILLING	SENT GAP/GINK	DC-22C	16600	PR RAP INTFLW	.9
	DRILLING	COMPOSITE WANP	DC-22C	16600	SENTINEL GAP	.8
	AIR-LIFT DEV	SENT GAP/GINK	DC-22C	16600	PR RAP INTFLW	-.9
	AIR-LIFT DEV	COMPOSITE WANP	DC-22C	16600	SENTINEL GAP	-1.0
DC-20C	AIR DRILLING	COMP WANP/GR	DC-1	32000	COMP WANP/GR	-3.0
	AIR DRILLING	PRIEST RAPIDS	DB-14	21700	PRIEST RAPIDS	-6.0
DC-19C	AIR DRILLING	PRIEST RAPIDS	DB-14	10000	PRIEST RAPIDS	-6.0
DC-22C	AIR DRILLING	PRIEST RAPIDS	DB-14	21700	PRIEST RAPIDS	-5.0
DC-19C/20C/22	AIR DRILLING	PRIEST RAPIDS	DC-16B	14000 - 16000	MABTON	-.9

* DISTANCES IN FEET, ESTIMATED FROM UNLABLED FIGURE (STRAIT, DECEMBER, 1985)
** ESTIMATED CHANGES IN FEET (ZEROS DO NOT INDICATE SIGNIFICANT FIGURES), NEGATIVE SIGN INDICATE WATER LEVEL DECLINES.

Most of the hydrochemical analyses documented to date rely heavily on major-ion and fluoride data, and there are significant differences in interpretation of these data. For example, in an unpublished review prepared for the Yakima Indian Nation, Lehman (1983) compiled a February, 1983 set of hydrochemical data prepared by BWIP and presented a discussion of the hydrochemical data based primarily on major-ion chemistry of the groundwaters. Figure 4.8 is a Piper Trilinear Diagram of the 1983 data, showing the major-ion relationships for waters from the Saddle Mountains, Wanapum and Grande Ronde Formations. Based on the major-ion chemistry, Lehman distinguished "Type A" (essentially $Na\text{-}HCO_3$ waters) and "Type B" (essentially $Ca\text{-}Mg\text{-}Cl\text{-}SO_4$ waters). The Type A waters are found in the Grande Ronde and portions of the Wanapum Basalts; the Type B waters are found exclusively in the Saddle Mountains Basalts near the margins of the Pasco Basin (i.e., near the presumed recharge areas for the Saddle Mountains Basalts). In addition, the trilinear diagram identifies mixing trends in both the cations and anions, and Lehman distinguishes a "Type C" water which is consistent with a mixing of Types A and B. The Type C water is identified in the Saddle Mountains and Wanapum Basalts in the central portion of the Pasco Basin, consistent with a zone of upwelling and mixing. Figure 4.9 is a southwest to northeast cross section of the Pasco Basin illustrating the distribution of major-ion water types based on the 1983 data. Lehman (1983) presents data to support a hypothesis that the distribution of the Type C (mixed) water is controlled by the distribution of the sedimentary interbeds of the Ellensburg Formation, not by the dense flow interiors of the basalts. As illustrated in the cross

FIGURE 4.8 MAJOR-ION RELATIONSHIPS

(after Lehman, 1983)



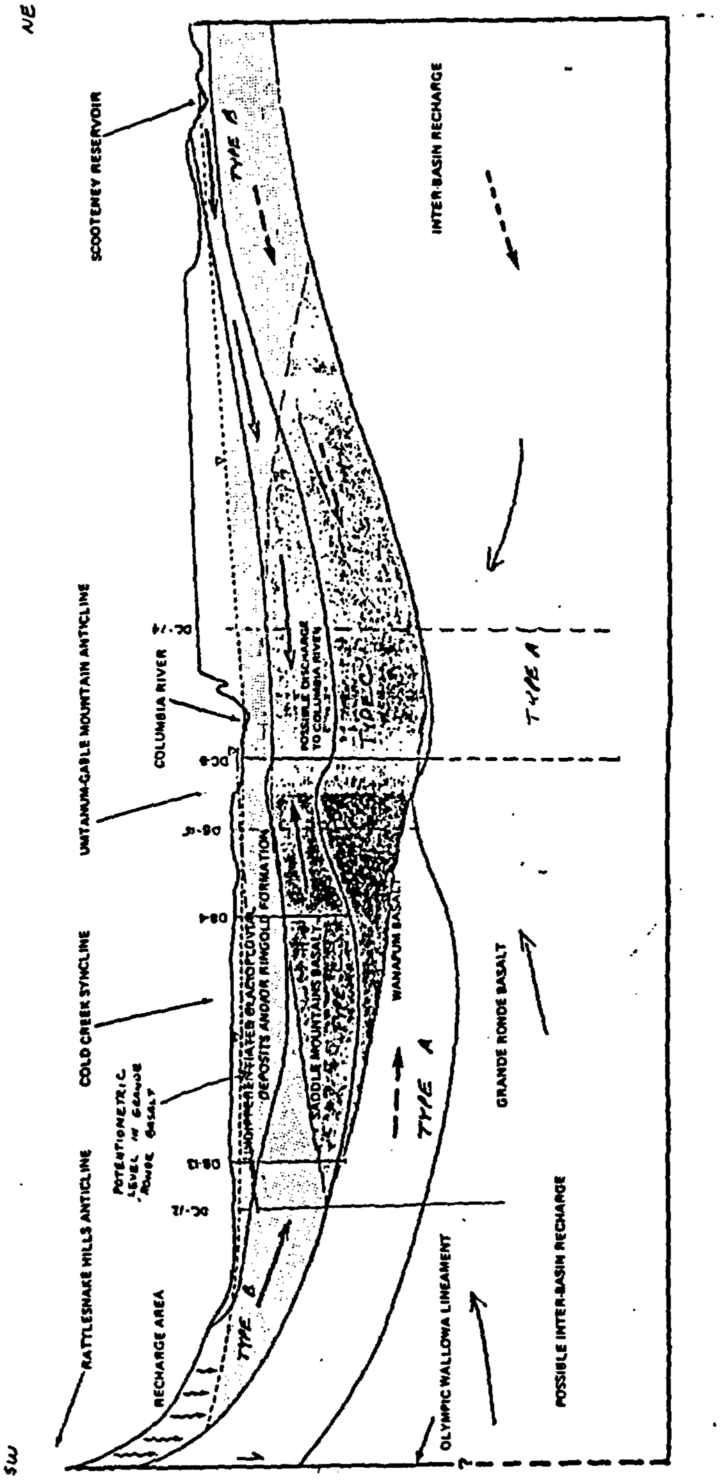
HYDRO-CHEMISTRY DATA PACKAGE
Piper Trilinear Plot of all data received from DOE Richland Office 2/15/83
(Charge Balance Error less than 10%, 11 samples excluded due missing data)

Linda L. Lehman

Date: March 17, 1983

FIGURE 4.9 VERTICAL SECTION SHOWING MAJOR-ION WATER TYPES

(after Lehman, 1983)



section, the trace of the Gable Mountain-Gable Butte anticline crosses the zone of Type C (mixed) water. If the anticline represents a structural discontinuity that permits significant vertical leakage, then this zone could provide a conduit for fluid flow, which could ultimately lead to discharge to the Columbia River northeast of the RRL.

In contrast to the analysis of Lehman, Williams and Associates (1985) determined that the three major geologic formations were distinguishable on the basis of their bulk chemistry and that there was no statistically discernible areal pattern to the hydrochemical data. These conclusions of Williams and Associates appear to be in conflict with the conclusions of Lehman (1983), although the problems that each considered were formulated in such different fashions that the conflict may reflect matters related to statistical methodology. It is clear from the dissolved gas data (not considered by either Williams and Associates or Lehman) that there are significant differences in the areal distribution of at least some chemical species (including some, such as nitrogen and argon, which should be highly conservative in the groundwater system). Additionally, the cluster analysis reported by Williams and Associates indicated "anomalous" placements for samples from boreholes DC-2, DC-6 and DC-14, which they ascribe to potential contamination or other sampling and analytical difficulties. However, Williams and Associates did not consider that these samples may represent a mixed water, as illustrated in Lehman's cross section.

The principal limitation of the hydrochemical analyses performed to date is that the analyses are limited to subsets of the hydrochemical data, typically relying heavily on major-ion chemistry. Because these ions are not generally conservative in a groundwater system, it is difficult to develop and test fully defensible mixing scenarios, which are obviously based on an assumption of conservation. Terra Therma considers that it is unlikely that additional hydrochemical and statistical analyses of the major-ion data will provide breakthroughs in understanding the chemical evolution of the groundwater system, and that attention should be focused on aspects of the groundwater chemistry which can be shown to provide unique signatures.

Key observations of hydrochemical responses that Terra Therma believes must be considered in utilization of conceptual models design include:

1. A high-nitrate plume in the unconfined aquifer and the upper several interbeds of the Saddle Mountains Basalt in the vicinity of the 200 West Area of the RRL.

2. A bimodal distribution of dissolved gas characteristics in the Grande Ronde, with a zone of high gas concentrations characterized by very high (>95 mol %) methane in and around the RRL and a zone of low gas concentrations characterized by very high (>95 mol %) nitrogen surrounding the high-methane zone.

3. Uncontaminated waters (i.e., waters with <5 mol % dissolved oxygen) in the Grande Ronde and Lower Wanapum containing excess helium and

anomalous ratios of nitrogen/argon which indicate that they are not receiving local recharge.

4. Evidence from both conservative and potentially non-conservative dissolved species of mixing in and above the Mabton Interbed over most, if not all of the Pasco Basin.

5. Evidence from both conservative and potentially non-conservative dissolved species of mixing in the Wanapum in the vicinity of the RRL and along the Umtanum Ridge-Gable Mountain anticline and possibly along the Benson Ranch syncline.

6. Distinct hydrochemical systems across the Cold Creek Barrier.

4.6 STIMULI

Numerous natural and man-induced environmental changes which could affect the BWIP groundwater flow system have been identified and investigated to some extent by DOE. Potential natural changes and processes that are subject to potential change include catastrophic Columbia River flooding, glaciation, precipitation, evapotranspiration, and tectonic or structural stresses. Man-induced changes include repository placement, dam construction, groundwater withdrawal, waste water disposal, irrigation return flow, and drilling activities.

All of these potential changes have been addressed to some degree by DOE in the SCR. Except for repository placement, historical and geological records have been studied and the information extrapolated to determine probabilities of future occurrence. Although considerable uncertainty exists in the probability determination for any of the potential changes, the uncertainty of how these changes might affect the groundwater flow system at the BWIP site is no less significant. In order to reduce this latter uncertainty, conceptual models of the groundwater flow system will have to be refined to the extent that the significance of any of these changes can be determined.

In the case of repository placement, case histories are not available to document likely processes and responses to burial. However, as with other potential changes which could affect the groundwater system, an understanding of the existing groundwater system, to the extent that bounding responses can be established, is of primary importance.

5.0 TERRA THERMA EVALUATION OF CONCEPTUAL FLOW MODELS

It is Terra Therma's position that there is currently insufficient data to allow development of a single conceptual flow model for the BWIP site. As with most hydrogeologic field problems, conceptual model development will be an ongoing activity to be refined as more data become available. A defensible model (or suite of models) will be established when uncertainties associated with each of the essential components (defined in Section 1.0) is reduced to an acceptable level, or if it can be shown that the model is based on assumptions which are conservative from the standpoint of repository performance.

Tables 2.1 through 2.6 indicate that concepts regarding the flow and transport dynamics of the BWIP site have changed through time (with the acquisition of data) and that disagreement continues to exist in the interpretation of the current database. However, for the various models proposed, there is general agreement among investigators for many components of the flow system. As a result of this agreement, we find it difficult to evaluate each model as a separate entity. We will therefore categorize the following evaluation on the basis of model components rather than the models themselves.

5.1 HYDROLOGIC FRAMEWORK

5.1.1 Concepts Having Relatively High Certainty

With regard to hydrologic framework, Terra Therma is in general agreement and associates a high level of certainty with the following interpretations:

Hanford and Ringold sediments comprise an unconfined aquifer system. The lower part of this system (lower Ringold) is locally semi-confined. Paleostream channels of higher transmissivity probably exist in the Hanford Formation which may result in preferred directions of groundwater flow. The unconfined aquifer constitutes a distinct hydrostratigraphic unit.

Columbia River Basalt is a layered system with a cumulative flow/interbed thickness exceeding 3,000 meters. Basalt flows have fairly uniform thicknesses and are normally laterally continuous over great distances within the Pasco Basin. Bedding orientations are nearly horizontal within the central portion of the Cold Creek syncline (including the RRL). A basalt flow typically contains a brecciated/vesicular flow top overlying a dense, less fractured interior, which in turn overlies a basal zone of glassy and sometimes rubblized basalt.

Flow tops form more or less continuous layers of variable thickness. They have relatively high transmissivity and are characterized by horizontal groundwater flow.

Flow interiors have relatively low bulk permeability and are characterized by vertical flow. They provide a certain degree of confinement to the basalt flow system. Intraflow features (e.g., zones of increased fracturing, pervasive joints, spiracles, etc.) have been identified within flow interiors. These features may result in increased rock permeability.

Flow bottoms are generally thin and are difficult to distinguish hydraulically from the underlying flow top.

In terms of horizontal hydraulic properties, interflows containing interbeds do not contrast greatly with interflows not containing interbeds.

Tectonic structures which cross-cut multiple flows probably exist within the Cold Creek syncline. These features may have lateral extents of many kilometers and vertical extents of hundreds to perhaps thousands of meters. It is generally presumed that these features are steeply dipping.

5.1.2 Unresolved Issues

Terra Therma considers the following concepts to be unresolved and may require additional evaluation:

Interflows are highly heterogeneous, at least on a small scale, with regard to physical and hydraulic properties. The effects of this heterogeneity on lateral flow/transport and the location of vertical leakage is not understood.

In basalt outcrops, flow interiors are observed to contain a variety of intraflow structures with variable scales and spacing. If some of these features have high permeability, it is possible for vertical hydraulic communication to exist between adjacent interflows even though most of the flow interior material is nearly impermeable. For permeable features having subvertical orientations, a limited suite of single hole tests conducted in vertical boreholes would not provide a statistical sampling of their hydraulic characteristics. There is currently no data to conclusively rule out the presence of such high permeability "windows" within basalt flow interiors.

The significance of distributed vertical leakage on the regional scale needs to be addressed. Although the average vertical flux per unit area may be small, the cross-sectional area available for leakage is very large, approaching many square kilometers. In addition, vertical leakage in structurally undisturbed areas may be enhanced by isolated high permeability features within flow interiors (discussed above), if they exist. In other basins within the Columbia River Plateau, the USGS considers basalt flow systems to be very leaky.

The significance of vertical leakage in anticlinal areas is uncertain. Most investigators postulate increased leakage in these areas, but the degree of increase is unspecified. In the extreme case of very high leakage, anticlinal areas could approach constant head boundaries to the basalt flow system.

5.2 PARAMETRIC INFORMATION

5.2.1 Concepts Having Relatively High Certainty

With regard to parametric information, Terra Therma is in general agreement and associates a high degree of certainty with the following interpretations:

The hydraulic conductivity of materials within the unconfined aquifer range from E-05 to E-02 m/s with higher conductivities generally characteristic of the Hanford Formation and lower values in the Ringold Formation. Specific yield ranges from .01 to .1, which is characteristic of fine to medium grained clastic materials.

A distinct permeability contrast exists between the bulk hydraulic conductivity of interflow materials (high) and that of flow interiors (low). This leads conceptually to a system of layered aquifers separated by aquitards.

Based on single hole tests, the hydraulic conductivity of interflows ranges over many orders of magnitude in each of the basalt units and variability within a unit is comparable to that existing between units. The geometric means of interflow hydraulic conductivity appear to be higher in Saddle Mountains and Wanapum Basalt and lower in Grande Ronde Basalt. However, the ranges of values in all three units overlap by many orders of magnitude.

Due to a preferred vertical orientation of fractures within the flow interiors, it is assumed that these materials are anisotropic with higher vertical hydraulic conductivity than that in the horizontal direction.

Most single hole tests conducted in flow interiors indicate extremely low horizontal hydraulic conductivity. However, two relatively moderate and one very high value have been reported.

5.2.2 Unresolved Issues

Terra Therma considers the following issues to be unresolved and may require additional evaluation:

There is a lack of spacial correlation in interflow hydraulic conductivity values obtained from single hole tests. As such, it is uncertain whether these data can be used to assign spacial distributions of characteristic (bulk) values to individual hydrostratigraphic units in basalt.

No defensible vertical hydraulic conductivity tests have been conducted within flow interiors. The large scale (bulk) vertical hydraulic conductivity of flow interiors is essentially unknown.

The hydraulic properties of intraflow structures within basalt flow interiors are unknown. If isolated, vertically oriented high permeability features exist within flow interiors, single hole tests conducted in vertical boreholes do not provide a statistical sampling of their hydraulic characteristics. For example, based on outcrop observations, it is stated in the DEA that spiracles should be anticipated at depth in Columbia River Basalt. However, no spiracles have been identified in any borehole drilled within the Hanford Reservation. It is possible that the occasional moderate and high hydraulic conductivities measured within flow interiors could represent isolated high permeability features.

Effective porosity of basalt interflows has been measured in only one location. Results of this tracer test are uncertain due to the testing methodology and conditions encountered. It is uncertain to what extent this measured value can be related to Columbia River Basalt in general.

Effective porosity of flow interiors is unknown. No tracer tests have been conducted in these layers.

Storativity can only be measured through the use of multiple borehole tests. Only four such tests have been conducted in Columbia River Basalt (three in the Priest Rapids unit and one in the McCoy Canyon interflow). It is uncertain to what extent these results can be applied to Columbia River Basalt as a whole.

5.3 BOUNDARY CONDITIONS

5.3.1 Concepts Having a High Degree of Certainty

With regard to boundary conditions, Terra Therma is in general agreement and associates a high level of certainty with the following interpretations:

> The upper boundary of the unconfined aquifer is the phreatic surface. The unconfined aquifer is laterally bounded by anticlinal uplands where the Hanford and Ringold Formations pinch out and/or the phreatic surface intersects the base of the hydrostratigraphic unit.
>
> The Columbia River constitutes a regional discharge boundary for the unconfined aquifer.
>
> Principal natural recharge to the unconfined aquifer takes place near its outer boundaries by direct infiltration of precipitation and by infiltration from ephemeral streams. Natural distributed infiltration within the central part of the Pasco Basin is considered negligible.
>
> Since the 1940's, significant artificial recharge has resulted from waste disposal operations in the 200 West Area, centering at U Pond.
>
> Within Columbia River Basalt, the Cold Creek Barrier appears to be a large scale impediment to lateral flow. It is probable that this feature can be considered a hydrologic boundary to the basalt flow system.

5.3.2 Unresolved Issues

Terra Therma considers the following issues to be unresolved and may require additional evaluation:

A lower hydrologic boundary for Columbia River Basalt needs to be defined with respect to the scale and performance of the repository. The recharge/discharge along an "effective" lower boundary needs to be addressed.

With exception of the Cold Creek Barrier, there is wide disagreement regarding lateral boundaries of the Columbia River Basalt. Some investigators feel that outcrop areas of the basalt formation constitute lateral boundaries. Others consider anticlinal areas and the Columbia River to represent regional hydrologic boundaries.

There is wide disagreement regarding the location and significance of recharge to the basalt flow system. Some investigators feel that outcrop areas are the major locations of recharge to Columbia River Basalt. Others feel that more significant recharge takes place by downward vertical leakage within the anticlinal areas and/or from the unconfined aquifer.

There is wide disagreement regarding the location and significance of discharge to the basalt flow system. Some investigators feel that major discharge occurs where basalt outcrops are in direct contact with major rivers. Others consider regional discharge to occur over a larger area indirectly into the Columbia River by upward vertical leakage into the unconfined aquifer.

5.4 HYDRAULIC HEAD RESPONSE

5.4.1 Concept Having Relatively High Certainty

With regard to hydraulic head response, Terra Therma is in agreement and associates a high level of certainty with the following interpretations:

Within the unconfined aquifer, hydraulic heads indicate that regional lateral groundwater flow is east from the RRL, then east-northeast towards the Columbia River.

Artificial recharge in the 200 West Area has created an extensive groundwater mound with a water table rise up to 24 meters. Radial flow away from this mound is superimposed on the regional flow direction.

In the 200 West Area, the potential exists for downward vertical flow from the unconfined aquifer into Saddle Mountains Basalt. This is due in part to the artificially created groundwater mound in the unconfined aquifer (described above).

In vicinity of the RRL, water levels measured in piezometer installations completed in the Mabton Interbed indicate a lateral flow direction to the west.

In vicinity of the RRL, water levels measured in piezometer installations indicate significant downward vertical gradients in Saddle Mountains Basalt.

In vicinity of the RRL, water levels measured in piezometer installations indicate very low horizontal and vertical hydraulic gradients in Wanapum and Grande Ronde Basalt. The vertical flow direction is interpreted to be upward.

Low horizontal and vertical hydraulic gradients apparently exist in Wanapum and Grande Ronde Basalt throughout the Cold Creek syncline.

Natural hydraulic head fluctuations within Columbia River Basalt appear to be slow and have small magnitudes.

Flowing artesian conditions have been observed in Columbia River Basalt in vicinity of the Columbia River.

Within Columbia River Basalt, a significant decrease in hydraulic head is observed across the Cold Creek Barrier from west to east. Significant water level fluctuations measured west of the structure are not observed on the eastern side.

Significant hydraulic head responses have been measured in observation wells and piezometers due to fluid injection or withdrawal during the drilling of test holes within the Hanford site.

These responses have ranged from .1 to 2 meters and have been observed up to 9.7 kilometers from the injection/withdrawal source.

5.4.2 Unresolved Issues

Terra Therma considers the following issues to be unresolved and may require additional evaluation:

With exception of the RRL area and borehole DC-1, hydraulic head measurements throughout the Hanford Reservation are based either on drill-and-test data or borehole installations with bridge packers and/or spot grout seals. Considerable uncertainty exists in hydraulic head data obtained in this manner, particularly with regard to assessing vertical hydraulic gradients. This type of head data is either uninterpretable or can be used only for the qualitative interpretations.

In many areas of the Hanford site, lateral and vertical flow directions cannot be determined because observed variations in water levels approach or exceed the uncertainties associated with the converting of those water levels to hydraulic head.

There is significant disagreement among various investigators regarding the relationship between vertical hydraulic gradients and magnitude of vertical leakage. Some consider low vertical gradients to indicate low vertical flux (leakage) rates. Others feel that the low gradients may in fact indicate a very leaky system.

Major disagreement exists in the interpretation of lateral flow directions in Columbia River Basalt. Some investigators consider lateral flow directions to be generally to the southeast. Others feel that flow directions cannot be determined from the current database.

5.5 HYDROCHEMICAL RESPONSE

5.5.1 Concepts Having a High Degree of Certainty

With regard to hydrochemical response, Terra Therma is in agreement and ssociates a high degree of certainty with the following interpretations:

Within the unconfined aquifer and the upper sedimentary interbeds of the Saddle Mountains Basalt, there is a plume of nitrate contamination that originated from the artificial recharge of the waste water disposal in the 200 West Area. The direction of flow is to the east and southeast, based on the nitrate distribution.

The dissolved gas compositions of groundwaters in the Grande Ronde Basalt defines two distinct hydrochemical zones:

A zone of high dissolved gas concentrations, in which the gas is dominantly ($>$ 95 mol %) methane, in and near the RRL;

A zone of low dissolved gas concentrations, in which the gas is dominantly (> 95 mol %) nitrogen, in all other parts of the Pasco Basin.

The argon/nitrogen ratios and helium concentrations of groundwaters in the Grande Ronde and Lower Wanapum Basalts are not consistent with local recharge.

The Cold Creek Barrier is reflected in the hydrochemical data, though inferences are limited by the small number of sample points northwest of the Barrier. The hydrochemical data do not throw significant light on the issue of how much, if any, flow crosses the barrier: the concentrations of all parameters of interest are much lower on the northwest side of the Barrier, which would permit substantial leakage to be masked by the much higher concentrations observed in the RRL boreholes. For example, the Cl concentration in the Lower Wanapum in the McGee Well is only 5 mg/L, while the concentration in RRL-2 is 350-450 mg/L. Clearly, a 10% leakage (a totally arbitrary number) of McGee Well water across the Barrier would be indistinguishable within the analytical precision of the Cl analyses and the variability of the Cl data within the RRL. However, the hydrochemical data do indicate that there can be very little leakage from the RRL to the northwest (even if this were energetically feasible), since this would have a significant effect on the observed chemistry.

Columbia River Basalt groundwaters have high pH values, indicative of extensive hydrolysis of silicates, probably of the glassy mesostasis. It is likely that the relatively high concentrations of Cl and F, particularly in the deeper units, are also related to the hydrolysis of glass.

The groundwater chemistry is consistent with a zone of mixing in the Saddle Mountains and Wanapum Basalts along the Umtanum Ridge-Gable Mountain Anticline.

Continuous flow in the Grande Ronde southeastward from the area of the RRL to DC-15 near the Columbia River is highly improbable based on the chemistry as reported.

5.5.2 Unresolved Issues

Terra Therma considers the following issues to be unresolved and may require additional evaluation:

There is disagreement between investigators on the extent to which there is consistent vertical distinctness between groundwaters in the major basalt units throughout the Pasco Basin. Because of the lack of consensus on distinctness, there is a consequent lack of consensus on the degree and extent (both vertical and lateral) of mixing of groundwaters. Terra Therma considers that the disagreement concerning distinctness is, at least in part, due to the evaluations that are based on inconsistent use of subsets of the hydrochemical data and divergent analytical methodologies.

There is disagreement about the use of distributions of potentially non-conservative dissolved species to identify directions of groundwater flow. Dissolved species which may be conservative in some groundwater systems (e.g., Cl, F), may not be conservative in the Columbia River Basalts due to hydrolysis of glassy mesostasis in the basalts.

There is disagreement on the origin of the methane in the high-gas waters in the vicinity of the RRL.

There has been no detailed analysis of the argon/nitrogen (or other noble gas) systematics to determine whether there are spacial distributions that shed light on the recharge/discharge relations in the Pasco Basin.

There is no consensus on whether groundwater age dating can be successfully applied to analyzing the flow system.

5.6 STIMULI

5.6.1 Concepts Having Relatively High Certainty

At this stage in the site investigation and conceptual model developement, there are no concepts which can be listed as having a high degree of certainty with respect to potential natural or man-induced changes which could affect the groundwater flow system at the BWIP site.

5.6.2 Unresolved Issues

Terra Therma considers the following issues to be unresolved and may require additional evaluation:

Potential natural changes which could affect the BWIP groundwater flow system have been identified and to some extent investigated. A high degree of uncertainty exists as to the probability and magnitude of the occurrence of any one of the events or processes. Historical and geological records have provided some information which can be extrapolated.

Potential man-induced changes have been identified, but the probability and magnitude of occurrence remain uncertain. Statistical analyses may be less successful in defining the probability of man-induced changes, resulting in a lower possible certainty than natural changes.

Regardless of the uncertainty of potential natural or man-induced changes, the uncertainty of the relevancy of these changes with respect to the groundwater system and EPA standards has not been investigated. It is anticipated that potential changes can be rated as to likely significance with respect to repository performance under EPA standards.

6.0 DATA ASSESSMENT NEEDS

In Section 5, unresolved issues are identified for each of the essential model components. In this section, the data assessments required to resolve these issues are evaluated. It is Terra Therma's position that unresolved issues need to be prioritized according to regulatory concerns of the NRC. If an issue is of critical concern in evaluating the EPA performance criteria, it is assigned a high priority. Low priority issues are those which have minimal impact on site performance. At the current level of conceptual model development for the BWIP site, considerable uncertainty exists in the significance of many issues affecting site performance. In the future, Terra Therma plans to conduct sensitivity studies using analytical and/or numerical methods to help prioritize the importance of unresolved issues. For example, even though the knowledge of a particular hydraulic parameter may be incomplete, analyses may show that "worst case" values are not significant in affecting repository performance. In this situation, it would be concluded that additional data for this parameter are not required. Conversely, if repository performance is sensitive to the parameter, then additional data would be required to better refine its value.

In this section, issues and associated data needs are classified in a preliminary manner as either "primary" or "secondary", depending on Terra Therma's subjective judgement of their relative importance. This prioritization is preliminary and subject to revision as more formal analytical evaluations are completed. Factors categorized under "primary" data assessment needs should not necessarily be interpreted as being items where more data is needed. Instead, it is Terra Therma's position that these factors require more detailed analyses to determine their significance and sensitivity in assessing repository performance.

6.1 FRAMEWORK

6.1.1 Primary Data Assessment Needs

FLOW INTERIOR HETEROGENEITY Repository performance relies to a great extent on the hydraulic confinement provided by basalt flow interiors. Observations of basalt outcrops indicate that flow interiors contain a variety of intraflow features with variable fracture frequencies and orientations. These include localized thinning of flow interiors, fanning entablature, vesicular zones, platy zones, pervasive sub-horizontal joints, spiracles, and others. Permeability contrasts between these features and the more typical colonnade-entablature have not been measured. If the permeability contrast is sufficiently great, it is possible that the regional hydraulic and transport characteristics of basalt flow interiors may be dominated by the properties of these features. This could result in hydraulic communication between interflows via more or less isolated high permeability "windows" through the flow interiors.

Since many of these features have a preferred vertical orientation, the past in situ test program, using vertical boreholes, has not provided a statistical sampling of their properties. For example, it is stated in the DEA that spiracles have not been identified in any borehole drilled within the Hanford site, even though their existence would be expected throughout Columbia River Basalt. The hydrologic properties of flow interior heterogeneities and the relative frequency of these features is a significant concern in evaluating site performance. Analyses are required to determine the sensitivity of repository performance to the frequency and hydraulic properties of these features.

TECTONIC STRUCTURES Tectonic structures are postulated to exist within the Cold Creek syncline. These may include conjugate strike-slip faults with lateral extents of tens of kilometers. The Cold Creek Barrier west of the RRL has a pronounced effect on the groundwater flow system and is interpreted to be an impediment to lateral flow. The Cold Creek Barrier was identified primarily because of the large hydraulic head change across the feature. Since head variations within the RRL and vicinity are very small, this type of interpretation is of limited use in identifying tectonic structures in this area. In addition, if some tectonic features have high permeability, they could in fact provide a mechanism for equalization of heads within the Cold Creek syncline.

The hydraulic impacts of tectonic structures within the RRL and vicinity (if they exist) could have a pronounced effect on regional hydraulics and contaminant transport. Thus, the possible existence and hydrologic properties of these features is a significant concern in evaluating site performance.

Site data and analyses are required to evaluate if such features are present in and around the RRL, and if so, to determine their potential impact on site performance.

REGIONAL LEAKAGE Vertical hydraulic gradients in deep basalt units within the Cold Creek syncline are small. This has been interpreted by DOE (1982) to indicate that there is very little vertical leakage within the RRL and vicinity. However, it is possible that vertical head equalization could in fact be the result of a leaky system. In studies of other basins within the Columbia Plateau, the USGS (1983) has interpreted basalt groundwater flow systems to be very leaky. If vertical leakage within the Pasco Basin is also significant, it could result (in part) from framework factors such as intraflow features within basalt flow interiors and tectonic structures (both described above). The nature in which leakage occurs has a strong bearing on contaminant transport and hence, repository performance. This could range from evenly distributed leakage through flow interiors to leakage occurring along isolated high permeability features. Analyses are required to evaluate the affects of hydrologic framework factors on regional leakage.

6.1.2 Secondary Data Assessment Needs

INTERFLOW HETEROGENEITY Single borehole tests have indicated that interflows are highly heterogeneous with regard to hydrologic properties. The scale and spacial variability of these heterogeneities are poorly understood. While such variability might not significantly effect the regional groundwater hydraulics, contaminant transport might be affected to a certain extent.

Analyses on interflow heterogeneity will be important for evaluating performance assessment modeling conducted by DOE.

ANTICLINE AREAS The significance of vertical leakage in anticlinal areas is uncertain. It is postulated that anticlines represent areas of increased vertical leakage, but the magnitude of this increase is uncertain. Since anticlines lie beyond the accessible environment, they are not a critical concern in repository performance. However, the presence of anticlines along the edges of the Pasco Basin could affect post repository conditions within the RRL. As a result, analyses on the hydrologic impacts of anticlinal areas may be of interest in repository performance.

6.2 PARAMETRIC INFORMATION

6.2.1 Primary Data Assessment Needs

VERTICAL HYDRAULIC CONDUCTIVITY OF FLOW INTERIORS No defensible in situ measurements of vertical hydraulic conductivity of basalt flow interiors have been accomplished at the BWIP site. A relatively small number of horizontal hydraulic conductivity measurements have been conducted in single boreholes. However, the relationship between these measurements and bulk vertical hydraulic conductivity is highly uncertain. DOE plans to conduct ratio tests as part of its large-scale testing strategy at the RRL-2 site. It should be recognized, however, that the ratio test will only measure the hydraulic properties of a relatively narrow vertical column of the instrumented flow interior. Terra Therma estimates that the lateral dimensions of this column may be, at the most, a few tens of meters. Because the ratio test measures hydraulic properties in a relatively small volume of rock, it does not provide bulk parameters suitable for performance assessment at the repository scale. It is unlikely that a properly conducted ratio test would be able to identify the existence of a high permeability feature more than several tens of meters away from the flow interior piezometer.

Because site performance is greatly dependent on confinement provided by flow interiors, the bulk vertical hydraulic conductivity of these hydrostratigraphic units are critical for assessing compliance with EPA performance criteria. Equally important is a knowledge of the heterogeneity of flow interiors with respect to vertical conductivity. This is because vertical contaminant transport could be dominated by the presence of isolated high permeability features, if they exist. As a consequence, analyses are needed to assess the significance of vertical hydraulic conductivity (magnitude and heterogeneity) on repository performance.

EFFECTIVE POROSITY The effective porosity of interflow materials has been determined at only one location and no measurements have been conducted within flow interiors. Effective porosity is a required parameter for modeling contaminant transport, and hence, is critical for analysis of repository performance. To date there is very little site-specific or generic data upon which effective porosity of Columbia River Basalt can be evaluated. Analyses should be conducted to determine which ranges of effective porosity have a significant effect on repository performance.

BULK INTERFLOW HYDRAULIC CONDUCTIVITY The vast majority of hydraulic conductivity values for basalt interflows have been obtained through the use of single borehole tests. These tests are point measurements and do not provide bulk parameter values. Because there is a lack of spacial correlation in hydraulic conductivities obtained from these tests, it is uncertain whether the data, in any way, can be used to assign distributions of bulk parameter values to associated interflows. Quantification of repository-scale flow models for performance assessment will require a knowledge of bulk hydraulic conductivity of interflows. Analyses are required to determine the relationship between heterogeneity and bulk hydraulic conductivity.

6.2.2 Secondary Data Assessment Needs

STORATIVITY Storativity (and specific storage) are hydraulic parameters that control the transient response of a groundwater flow system. A knowledge of this parameter will not be required for most pre-emplacement (steady state) analyses. However, storativity may play an important role in assessing post-emplacement scenarios (e.g., repository resaturation, thermal effects). Only a limited number of storativity measurements have been accomplished within the Hanford site, with only one test having been conducted in Grande Ronde Basalt. The effect of storativity on transient performance assessments should be evaluated.

6.3 BOUNDARY CONDITIONS

6.3.1 Primary Data Assessment Needs

LATERAL BOUNDARIES Since all known lateral boundaries are beyond the accessible environment boundary, there are no primary data needs associated with these features.

LOWER HYDROLOGIC BOUNDARY A philosophical consensus needs to be established regarding adoption of a lower boundary to the Columbia River Basalt for performance assessment. Analyses might be conducted to determine at what minimum depth this boundary would have a minimal effect on pre- and post-emplacement performance modeling.

6.3.2 Secondary Data Assessment Needs

GABLE MOUNTAIN ANTICLINE Hydrologic effects of the Umtanum Ridge-Gable Mountain anticline could have a significant impact on post-emplacement conditions within the RRL and vicinity. For example, if this feature is characterized by high leakage and low recharge, depressurization associated with the repository (prior to resaturation) could propagate laterally to the anticline, vertically upward to shallower hydrostratigraphic units, and finally laterally back towards the RRL. Conversely, if this feature has high leakage and high recharge, it may operate as a nearly constant head boundary, in which case, depressurization associated with the repository might be attenuated to some extent in shallower units. Analyses to quantify the above scenarios should be considered to determine if field characterization of this feature is necessary.

COLD CREEK BARRIER There is considerable circumstantial evidence to indicate that the Cold Creek Barrier has a significant impact on regional flow within the Cold Creek syncline. It is considered a probability that this feature is an impediment to lateral groundwater flow. Since the Cold Creek Barrier will probably be modeled as a no-flow boundary, analyses might be performed to assess the sensitivity of this assumption on performance modeling.

TECTONIC STRUCTURES If field testing were to identify the presence of a tectonic structure within the RRL and vicinity that had a substantial impact on groundwater flow (i.e., behaved as an internal hydrologic boundary), analyses would be required to determine the sensitivity of such a feature on site performance.

6.4 HYDRAULIC HEAD RESPONSE

6.4.1 Primary Data Assessment Needs

HYDRAULIC HEADS In deeper basalt units, the measured variations in water levels and downhole pressures are comparable to the uncertainties associated in converting those measurements to hydraulic heads. Thus, while it can be concluded that horizontal and vertical hydraulic gradients are low, the actual flow directions and flux rates are uncertain. Although it may not be necessary to know these factors for performance assessment (particularly for post-emplacement scenarios), a more detailed understanding of the relationships between field measurements and in situ hydraulic heads are required. At a minimum, this understanding should be sufficient to allow for calculation of minimum/maximum gradients and extremes in flow directions.

MAN-INDUCED TRANSIENTS Pre-emplacement groundwater travel times assume that the flow system is close to steady state and approximates natural conditions that will eventually be re-established after repository closure. It is possible that man-induced transient stresses currently exist in the Pasco Basin. If these stresses are significant, the reliability which can be placed on the pre-emplacement travel time criteria will be subject to uncertainty. A major concern is the development of an artificial groundwater mound in the unconfined aquifer and if this has resulted in pressure perturbations in Columbia River Basalt. Other transients may result from groundwater withdrawals and surface irrigation outside the Hanford Reservation and the construction of dams on the Columbia River. Analyses may be required to assess the significance of these activities on current hydraulic heads within the RRL and vicinity.

6.4.2 Secondary Data Assessment Needs

Terra Therma has not identified any secondary data assessment needs associated with hydraulic head response.

6.5 HYDROCHEMICAL RESPONSE

6.5.1 Primary Data Assessment Needs

HYDROCHEMICAL PARAMETERS In order to use hydrochemical data as a response set to test ("calibrate" or "validate") models of the groundwater flow system, there should be a set of hydrochemical parameters that can be defensibly used to address distinctness, mixing and dilution without the need (or with minimum need) for complex geochemical modeling to consider reaction mechanisms and paths.

ORIGIN OF METHANE Because the high gas content/high methane zone in the vicinity of the RRL has been interpreted as indicating high vertical leakage, the origin of the methane may be important in determining the extent of the flow system that is involved in the methane-rich subsytem.

6.5.2 Secondary Data Assessment Needs

NOBLE GAS SYSTEMATICS Noble gases, because they are so unreactive, have been used in numerous hydrogeologic studies as natural tracers. A relatively simple assessment, for example of argon/nitrogen ratios, could be conducted to determine the usefulness of this data at identifying vertical and lateral spacial variations.

GROUNDWATER AGE DATING Efforts to use carbon-14 methods to date groundwater have encountered severe defficulties, due primarliy to the presence of methane in the groundwater system (NRC, 1983). Preliminary work has been done on data collection and analyses for other dating techniques, including Cl-36 and uranium disequilibrium methods. It is anticipated that DOE will continue with this application of isotope hydrology to support analyses of the degree of isolation present in the groundwater system and, possibly as indirect support for analyses of groundwater travel times. Analyses of groundwater dating techniques and of the data collection and analytical requirements may be required to evaluate the work being conducted by DOE and to be able to use the age-dating data in a chemical-response model.

6.6 STIMULI

6.6.1 Primary Data Assessment Needs

It is Terra Therma's opinion that there are no primary data assessment needs associated with natural or man-made pre-emplacement stimuli. Post-emplacement stimuli (such as repository dewatering and thermal loading) are not considered as separate issues, but are preferably incorporated into the analyses of other data assessment needs.

6.6.2 Secondary Data Assessment Needs

SIGNIFICANCE OF NATURAL AND MAN-INDUCED TRANSIENTS The significance of potential natural or man-induced changes to the performance of the RRL has not been investigated. Although the probability and magnitude of these potential changes are important, the relevancy of these changes to repository performance is considered a primary information need. Analyses can be performed to identify bounding conditions for such changes, and therefore determine their likely significance. The significance of any one potential change will determine what further investigation, if any, is needed in reducing the uncertainty of its probability and magnitude of occurrence.

However, in order to establish bounding conditions for each potential change, the conceptual model of groundwater flow from a performance perspective has to be better defined than exists at present. Although the data need described above is considered to be primary, it is dependent upon other data needs described in this document.

PROBABILITY AND MAGNITUDE OF OCCURRENCE Should any of the potential natural or man-induced changes prove to be signficant with respect to EPA performance of the repository, remaining uncertainties regarding the probability and/or magnitude of occurrence should be reduced to acceptable levels.

7.0 WORK PLANS

This Section describes analytical and/or numerical evaluations which Terra Therma plans to utilize in assessing the primary data needs discussed in Section 6. The approach is not to simply itemize where data are lacking, but rather to determine which data are specifically required by the NRC to reach decisions on licencing. For the most part, analyses for a particular parameter will involve a two-phase process:

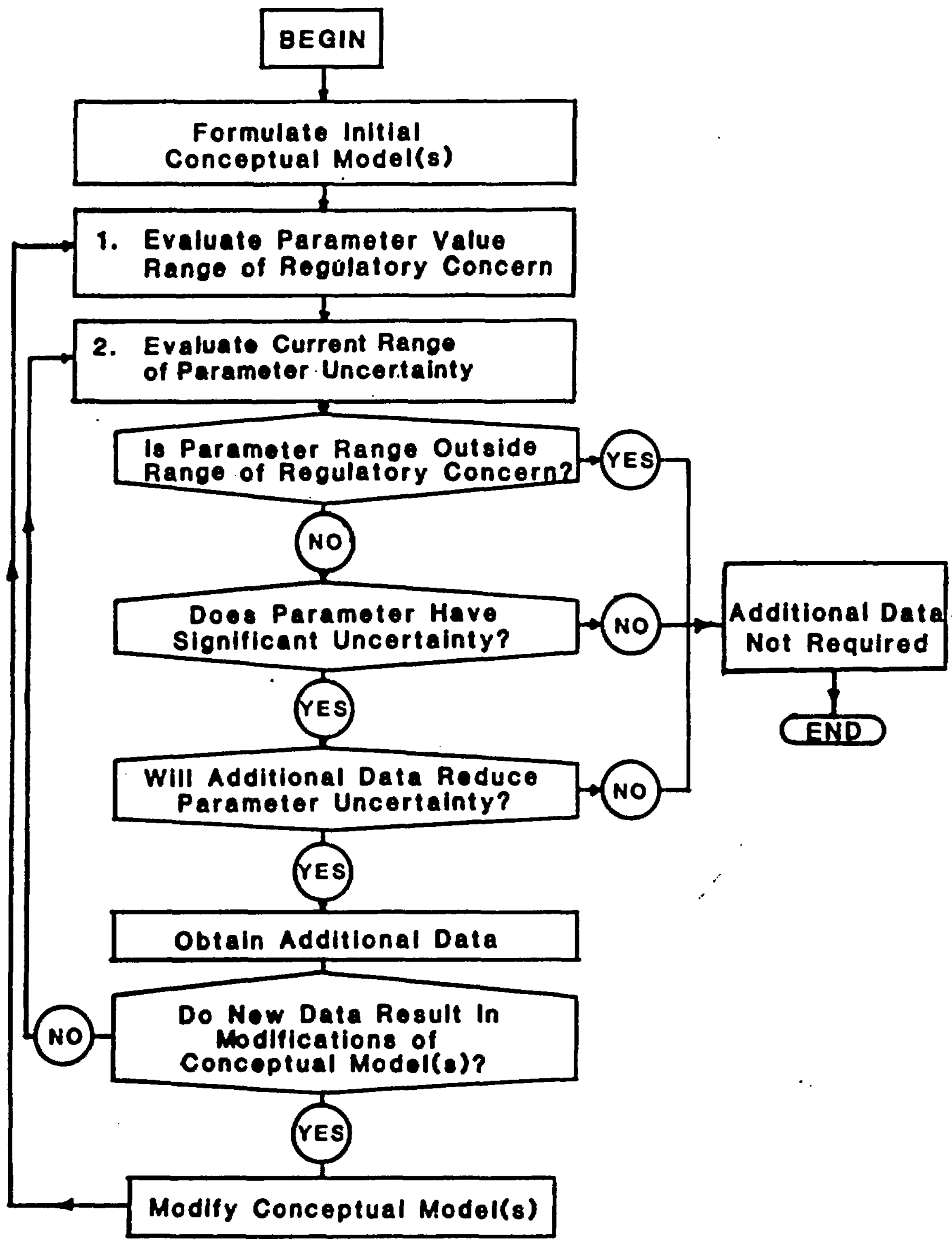
1. Sensitivity studies to determine what value range of the parameter is a significant concern in evaluating NRC's performance criteria.
2. Analyses to determine the current degree of uncertainty of the parameter, based on existing field or generic data.

After these analyses are completed, Terra Therma will evaluate whether additional field data are needed (1) to reduce uncertainty in the parameter value or (2) to verify that the parameter is outside the range of regulatory concern. If, for example, it is apparent that a parameter for the BWIP site clearly falls outside the range of regulatory concern, it will be concluded that future field testing for this parameter is not required. Future testing also might be unnecessary for a parameter which is inside the range, but has relatively high certainty (e.g., additional data will not refine the parameter value). However, if a parameter has relatively high uncertainty and potentially lies within the range of regulatory concern, it may be concluded that additional field or generic data are required in order for the NRC to evaluate associated performance criteria.

It is recognized that DOE is in the process of developing plans for future testing at the BWIP site. These include large-scale hydraulic stress (LHS) tests to be conducted at the RRL-2 site and also testing performed in the exploratory shaft. An important aspect of Terra Therma's evaluation will be to judge the effectiveness of DOE's proposed tests in providing data which the NRC needs to reach its licencing decisions. As additional testing is conducted at the BWIP site, the uncertainty associated with key parameters will be modified (and hopefully reduced). It is Terra Therma's position that data needs assessment will be an on-going process as additional testing is performed. The flow chart illustrated in Figure 7.1 shows the logic that Terra Therma would consider necessary to evaluate the data needs of a particular parameter throughout the site characterization program.

For the purpose of assessing data needs, it is Terra Therma's position that most analyses can be accomplished using analytical solutions and occasionally simple numerical models. It will not be the purpose of these analyses to simulate site performance in detail, but rather to evaluate the sensitivity of key parameters in meeting or violating site performance criteria. Our experience has shown that such sensitivity studies can often be performed in a conservative manner without consideration of all details of the flow/transport system. Furthermore, the use of sophisticated analytical/numerical models will not necessarily reduce uncertainty of the simulated result when key input

FIGURE 7.1 LOGIC FOR EVALUATION THE DATA NEEDS OF A PARTICULAR PARAMETER



parameters are at best order of magnitude estimates (which we consider to be the case at BWIP). Thus, it is Terra Therma's philosophical approach to give priority to using simple solutions unless it is demonstrated that such solutions are nonconservative and/or do not incorporate key aspects of the flow/transport system required to assess the associated data need.

The work plans presented in this section deal with primary data assessment needs described in Section 6. We consider secondary data needs to be of lower priority and work plans for these items will not be addressed in this section. The plans proposed here are preliminary and subject to revision. It is likely that many aspects of the proposed work will be modified in response to new data, modification of conceptual models, and shifting of regulatory priorities. The described tasks provide the framework for directing Terra Therma's future work. However, sufficient flexibility is also required so that technical direction of the project is responsive to the NRC's regulatory concerns.

7.1 FRAMEWORK

7.1.1 Flow Interior Heterogeneity

SENSITIVITY ANALYSIS Analyses will be performed to test the sensitivity of high permeability features on regional leakage and transport. The analytical model will consider steady state groundwater flow through a basalt flow interior which separates two adjacent interflows maintained at different hydraulic heads. The flow interior will consist of two materials: (1) a low permeability type which represents the majority of the flow interior and (2) a high permeability type which is associated with high permeability features. It is recognized that the observed bulk vertical hydraulic conductivity of the flow interior could result from a large number of low to moderate permeability features or a small number of very high permeability features. The purpose of these analyses will be to learn what combinations of frequency and permeability can result in the range of bulk vertical hydraulic conductivities thought to exist at the Hanford site. Once these relationships are established, further analyses will be performed to calculate the mass flux of contaminants through the flow interior for various possible combinations of frequency and permeability.

UNCERTAINTY ANALYSIS The results of single borehole tests conducted within basalt flow interiors have been incorporated into the Terra Therma Database. Statistics will be applied to all or subsets of the resulting hydraulic conductivities to determine geometric means, standard deviations of the log, tests of significance, etc. A similar evaluation will be made of effective porosity using actual site data and/or generic information.

7.1.2 Tectonic Structures

SENSITIVITY ANALYSIS Using simple analytical models, the effect of through-going tectonic structures on radionuclide transport will be evaluated. These calculations will consider steady state groundwater flow, head conditions existing in the RRL, and possible ranges in hydraulic conductivity for tectonic breccia. Ranges for effective porosity and other transport related parameters will also be considered. The sensitivity of cumulative flux rate vs. time will be determined for each of the key hydraulic and transport parameters.

UNCERTAINTY ANALYSIS The Terra Therma Database will be reviewed to determine which in situ tests have been conducted in known or possible tectonic breccia within the Hanford site. If a sufficient number of cases are identified, statistical analyses will be performed to determine geometric means, standard deviations of the log, and tests of significance. If only a limited number of cases are identified, an attempt will be made to use generic data.

7.1.3 Regional Leakage

SENSITIVITY ANALYSES The significance of vertical leakage on the regional scale can probably be evaluated using a simple two-dimensional analytical or numerical model oriented in a vertical plane. The model will incorporate a layered sequence of aquifers (interflows) separated by aquitards (flow interiors), and appropriate boundary conditions. Modeling runs will be made to determine the relationship between bulk vertical hydraulic conductivity and the degree of regional leakage. In addition, the range of vertical conductivities resulting in vertical equalization of heads will also be assessed.

Assessment of local leakage in Saddle Mountains Basalt may be possible by considering possible downward pressure perturbations associated with development of the groundwater mound in the unconfined aquifer. An attempt would be made to determine if known downward hydraulic gradients within the Saddle Mountains (in vicinity of the RRL) can be correlated with head increases known to have occurred along the upper boundary of the unit. This analysis can probably be accomplished using an axisymetric analytical or numerical flow model. Modeling runs will be made to determine the ranges of vertical hydraulic conductivities which would or would not result in significant downward hydraulic responses.

UNCERTAINTY ANALYSIS This evaluation will involve determination of vertical hydraulic gradients within the RRL and vicinity. Most of the data required for this purpose is available in the Terra Therma Database. An attempt would be made to estimate minimum, maximum, and median vertical hydraulic gradients within major hydrostratigraphic units.

7.2 PARAMETRIC INFORMATION

SENSITIVITY ANALYSES The sensitivities of bulk vertical hydraulic conductivity of flow interiors, bulk horizontal hydraulic conductivity of interflows, and effective porosities of both interflows and flow interiors will be evaluated using analytical and possibly simple numerical flow models. In its most simple form, the flow model will consist of a two-dimensional analytical solution in which the flow region is oriented in a vertical plane. The model will incorporate a layered system of aquifers (interflows) separated by aquitards (flow interiors). This is similar to the approach used in Appendix D of the BWIP Site Characterization Analysis (NRC, 1983). If required, increasing levels of sophistication could be accomplished using models ranging from a vertically oriented two-dimensional numerical model to a quasi-three-dimensional numerical model. The latter model would have the capability of simulating lateral heterogeneity in hydraulic properties.

Sensitivity analyses will be performed by varying hydraulic parameters and calculating radionuclide travel times and flux rates, which in turn will be compared to performance criteria. If possible, an attempt will be made to simulate post-emplacement conditions by introducing internal sources/sinks and modifying boundary conditions.

7.2.1 Vertical Hydraulic Conductivity of Flow Interiors

UNCERTAINTY ANALYSIS Because no defensible in situ measurements of bulk vertical hydraulic conductivity have been conducted at the BWIP site, the uncertainty of this parameter can not be evaluated using the current database. A speculative range of values may be attempted by statistical analysis of single borehole tests conducted within flow interiors (horizontal hydraulic conductivities). It is anticipated that direct measurements of vertical hydraulic conductivity of some flow interiors will be accomplished during LHS testing and from tests conducted in the exploratory shaft. Thus, more definitive uncertainty analyses of this parameter will be possible in the future.

7.2.2 Effective Porosity

UNCERTAINTY ANALYSIS Because effective porosity has only been measured in one location within Columbia River Basalt, the uncertainty of this parameter cannot be evaluated. It is also difficult to determine a range of generic values, since contaminant transport is, in large part, fracture controlled. DOE plans to conduct additional tracer tests as part of the LHS and exploratory shaft testing programs. Thus, more definitive uncertainty analyses of this parameter will be possible in the future.

7.2.3 Bulk Interflow Hydraulic Conductivity

UNCERTAINTY ANALYSIS Hydrologic tests conducted within basalt interflows have primarily consisted of a large number of single borehole tests. A sufficient number of single borehole tests have been conducted to allow for statistical analysis, but there are major uncertainties in the representativeness of hydraulic conductivity values measured by this method. Statistical parameters, such as geometric means, standard deviation of the log, and tests of confidence, will be derived for all or subsets of the single borehole test data currently on file in the Terra Therma Database. However, it must be recognized that estimation of bulk hydraulic conductivities from these point measurements has a high degree of uncertainty. In addition, because the results of single borehole tests show little or no spacial correlation, it will probably not be possible to use these data to assign spacial distributions of bulk hydraulic conductivity at scales required for performance modeling.

In addition to single borehole tests, a small number of multiple borehole tests have been performed by DOE. These include three tests in the Priest Rapids Member and one test conducted in the McCoy Canyon Interflow. Hydraulic conductivities determined from multiple borehole tests represent integrated values over a relatively large area, and are thus suitable for estimating the bulk values required for performance modeling. Unfortunately, the limited number and distribution of multiple borehole tests performed to date do not permit sufficient characterization of interflow properties to allow for reliable uncertainty analyses. DOE's planned LHS testing program will involve a number of multiple borehole tests, some of which will be conducted at the repository scale. More definitive uncertainty analyses will be possible upon completion of these tests.

As discussed in Section 4.5.1, fluid injection/withdrawal associated with drilling on the Hanford site has resulted in measurable hydraulic responses in observation wells and piezometers. Table 4.1 summarizes the location of drilling activities and the magnitude and locations of observed hydraulic head changes. These experiences can be considered inadvertent multiple borehole tests which, under appropriate conditions, are suitable for analysis of bulk hydraulic parameters. An example of such an analysis is provided by Lu (1984). Terra Therma will review drilling data and observed hydraulic head variations to identify which responses are suitable for analysis. These data will then be analyzed using an analytical simulator which can account for variable injection/withdrawal rates at the drilling location. Initially the simulator will contain an algorithm to predict the theoretical response of an ideal confined aquifer at the observation well of interest. Values of transmissivity and storativity will then be estimated by trial-and-error comparison between the theoretical and measured response. If appropriate, the analyses can be extended to include leaky aquifer conditions and simple hydrologic boundaries. It is hoped that these calculations will provide bulk hydraulic conductivity and storativity values for several interflows, which can be used in uncertainty analyses and also provide input data to performance models.

7.3 BOUNDARY CONDITIONS

7.3.1 Lower Hydrologic Boundary

SENSITIVITY ANALYSIS Definition of an effective lower boundary to the basalt flow system is not considered a major concern in performance assessment of pre-emplacement conditions. However, during post-emplacement thermal loading, hydrostratigraphic units below the repository may be an important source of groundwater. To evaluate the depth of an effective lower hydrologic boundary, Terra Therma would perform analyses to evaluate groundwater flow below the repository during maximum thermal loading. This will involve a two-dimensional analytical or possibly numerical model oriented in a vertical plane. Analyses will generally involve planar flow, but in some cases, axisymetric conditions might be assumed. The model would incorporate a layered system of aquifers (interflows) separated by aquitards (flow interiors). Thermal effects will be directly incorporated into the model or simulated in an approximate manner using a distribution of source/sink terms. Modeling runs will be performed using different depths for the lower boundary to determine the minimum depth at which the boundary has negligible effect on performance calculations.

UNCERTAINTY ANALYSES For this task, uncertainty analyses will generally involve range estimates of hydraulic parameters for basalt units below the candidate repository horizon.

7.4 HYDRAULIC HEAD RESPONSE

7.4.1 Hydraulic Heads

SENSITIVITY ANALYSES Evaluations will be performed to determine the sensitivity of borehole fluid properties on conversion of water levels to in situ hydraulic heads. This will involve consideration of the effects of temperature, dissolved gas, and salinity on fluid density within an observation borehole or piezometer installation. It is anticipated that the HEADCO program (once validated) will be used in this assessment. In addition, the effects of borehole construction on determination of hydraulic heads will also be considered. This may include quantification of errors resulting from grout seals having finite permeability and the use of bridge packers with spot-grouted seals. The overall purpose of the above calculations will be to quantify an error range associated with conversion of water levels to heads.

UNCERTAINTY ANALYSIS Horizontal and vertical hydraulic gradients will be evaluated using water level information contained in the Terra Therma Database. Based on results of the sensitivity analyses discussed above, error ranges in calculated hydraulic gradients will be assessed. Variations in possible gradient directions will also be evaluated. If possible, an attempt will be made to assign probabilities to variations in possible magnitudes and directions of the hydraulic gradient.

7.5 HYDROCHEMICAL ANALYSES

In the context of evaluating conceptual models at the scale of repository performance against the EPA Standard, Terra Therma considers hydrochemical information to fall into the "Response" category. That is, the data would be used to evaluate the validity of an analytical or numerical realization of a conceptual model of the BWIP site, rather than to determine the probable performance of the repository.

There is a body of hydrochemical data - the analytical data on ligands in solution that are potentially important to transport of radionuclides - that is susceptible to the sort of sensitivity/uncertainty analyses that have been proposed above for aspects of the conceptual model. However, it is the understanding of Terra Therma that this sort of analysis is, generally speaking, out-of-scope for the current contract, being rather, the responsibility of technical assistance contractors in geochemistry.

Terra Therma considers that analyses of the hydrochemical data assessments described in Section 5.5 above are best done as simple statistical and chemical analyses within the framework of updates to the conceptual model evaluations, rather than in the framework of Subtask 2.5.

7.6 STIMULI

Since there are no primary data assessment needs associated with pre-emplacement stimuli, sensitivity and uncertainty analyses for this factor are not considered necessary at this time. Sensitivity studies of post-emplacement stimuli (repository dewatering and thermal loading) will be considered in analyses associated with other conceptual model factors.

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